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Retrofitting POTWs

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Handbook

Retrofitting POTWs

U.S. Environmental Protection Agency
Office of Research and Development

Center for Environmental Research Information
Cincinnati, OH 45268

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Major Authors:
Bob A. Hegg, Larry DeMers, John Barber - Process Applications Inc., Ft. Collins, Colorado

Contributing Authors:
Edwin F. Barth, Jr. - Barth Tec, Inc., Cincinnati, Ohio
David T. Chapman - Canada Centre for Inland Waters, Burlington, Ontario
Dals Chaudhary - Hazen and Sawyer, New York, New York
Alan Cooper - Black and Veatch, Inc., Rockville, MD
Glen Daigger - CH2M Hill, Denver, Colorado
E. J. Middlebrooks - University of Tulsa, Tulsa, Oklahoma
Ms. Tyler Richards - Pollution Control Bureau, Atlanta, Georgia
Rudy J. Tekippe - James M Montgomery Engineers, Pasadena, California
Ronald F. Wukasch - Purdue University, West Lafayette, Indiana
James Young - University of Arkansas, Fayetteville, Arkansas
Sherwood Reed - U.S. Army Corps of Engineers, Hanover, New Hampshire

Reviewers:
Richard C. Brenner - U.S. EPA-RREL, Cincinnati, Ohio
Arthur J. Condren - James M. Montgomery Engineers, Pasadena, California
James A.Heidman - U.S. EPA-RREL, Cincinnati, Ohio

Peer Reviewers:
Eric Cohen - U.S. EPA, Office of Water, Washington, DC
Charles Conway - U.S. EPA-Region 1, Boston, Massachusetts
John Esler - NYS Dept. of Environmental Conservation, Albany, New York

Technical Direction/Coordination:
James F. Kreissl - U.S. EPA-RREL, Cincinnati, Ohio
Denis J. Lussier - U.S. EPA-CERI, Cincinnati, Ohio

Chapter 1
Introduction

1.1 Purpose

This manual is intended as a source document for individuals responsible for improving the performance of an existing, non-complying wastewater treatment facility. Described are: 1) methods to evaluate an existing facility's capability to achieve improved performance, 2) a process for systematically improving its performance, and 3) details on how to modify the facility to achieve the required levels of performance. The manual emphasizes meeting National Pollutant Discharge Elimination System (NPDES) permit requirements for secondary treatment facilities (30 mg/L BOD_5 and TSS). Though the manual is not intended to describe cost saving options or to present alternatives for designing new facilities for expansion purposes (i.e., to provide increased hydraulic and/or BOD loading capacity), in some cases the approach and modifications described may result in cost savings and/or increased capacity.

1.2 Background

The need for better treatment performance from existing facilities is widespread. Usually the most cost effective approach for owners to achieve compliance is to optimize existing facilities either in terms of capital or operational improvements. Recent events have provided impetus to this approach by increasing incentives for improving existing plant performance.

The 1986 Needs Survey (1), conducted by the U.S. Environmental Protection Agency (EPA), identified 10,131 of 15,438 operating treatment plants as having documented water quality or public health problems. The study determined that $36.2 billion is needed to meet the needs of secondary treatment, advanced treatment, infiltration/inflow, and new interceptor sewers. However, the funds available to support these projects are decreasing. Directions provided by the Clean Water Act (CWA) (2), which became law in February 1987, increased local responsibility for financing wastewater treatment projects by decreasing grant funding. The CWA provided $9.6 billion for construction grants, which falls short of the projected needs. A major aspect of the CWA was that these grants would end after 1990.

An alternative source of funding assistance was addressed by the CWA and involved providing seed money for state implemented, revolving loan programs. Funds allocated for this program are as follows: $1.2 billion annually for FY 89 and FY 90; $2.4 billion for FY 91; $1.8 billion for FY 92; $1.2 billion for FY 93; and $0.6 billion for FY 94 (a total of $7.2 billion). Even with these funds, the requirements identified in the Needs Survey will not be met.

The combined effects of a significant need for capital improvements at wastewater treatment projects, decreased grant funding, and more local responsibility for financing encourages optimization of existing facilities.

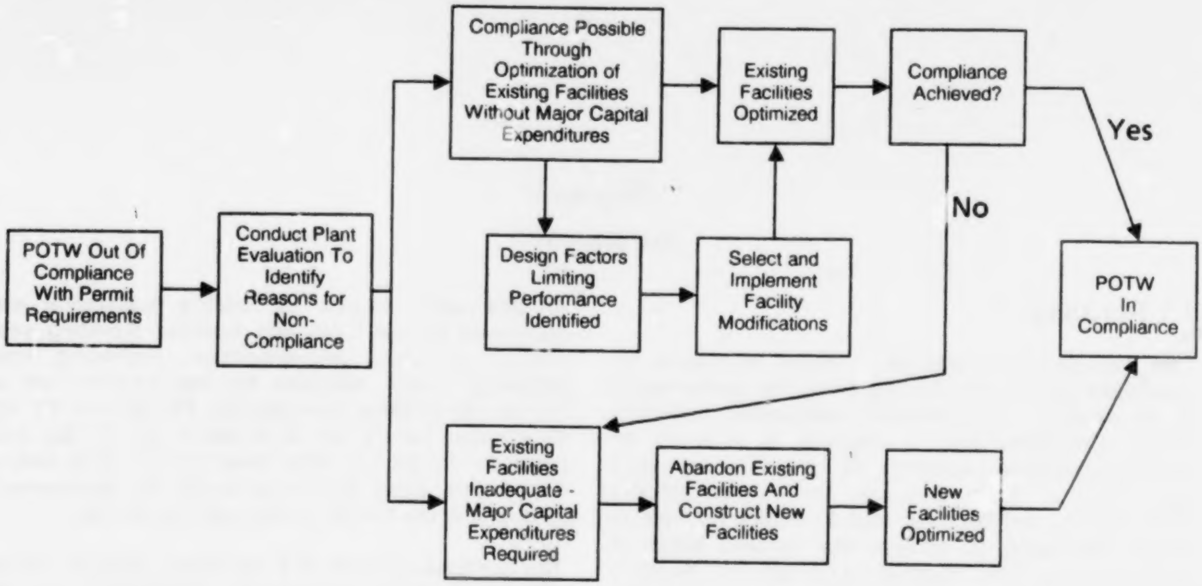
Large numbers of wastewater treatment plants are still in serious violation of final effluent permit requirements. A Management Advisory Group, consisting of an independent group of wastewater professionals, examined the municipal compliance picture for the U.S. EPA. Their 1987 report (3) indicated that the percentage of major dischargers still not in compliance could be as high as 37 percent.

U.S. EPA's National Municipal Policy, issued in early 1984, called for every wastewater treatment system to be in compliance with permit requirements by July 1, 1988 (4). A major provision of the Policy was the requirement of a non-complying facility to develop a Composite Correction Plan. The purpose of this plan was to identify the causes of non-compliance and to outline corrective actions and a schedule for completing the corrective actions in order to achieve compliance. Provisions were also required in the plan for interim steps to optimize existing facilities. As such, the Policy focuses heavily on optimizing existing facilities.

1.3 Scope

Figure 1-1 depicts the methodology for achieving POTW compliance used in this manual. As shown, an evaluation procedure must be implemented to establish existing facility capability. An evaluation approach called a Comprehensive Performance Evaluation (CPE) is described in Chapter 2. If compliance appears possible through optimization of

Figure 1-1. Methodology for achieving POTW compliance.



POTW Out Of Compliance With Permit Requirements
Conduct Plant Evaluation To Identify Reasons for Non-Compliance
Compliance Possible Through Optimization of Existing Facilities Without Major Capital Expenditures
Existing Facilities Optimized
Compliance Achieved?
Yes
No
Design Factors Limiting Performance Identified
Select and Implement Facility Modifications
POTW In Compliance
Existing Facilities Inadequate - Major Capital Expenditures Required
Abandon Existing Facilities And Construct New Facilities
New Facilities Optimized

existing facilities, then a systematic approach to address identified deficiencies should be implemented to achieve compliance (i.e., Chapter 3 - Composite Correction Program [CCP]). If compliance has not been achieved after completing the evaluation step and implementing corrective actions to optimize performance of the existing plant, facility modifications are indicated. Either: 1) totally new facilities must be designed and constructed or 2) capital expenditures must be made at the existing facility. A fundamental difference between these options is that the first approach includes activities that assess the need for increased capacity as well as improved performance, and includes an alternative analysis that may lead to abandoning present facilities. The second approach, a facility modifications or retrofit approach, emphasizes existing facility changes to meet desired performance with current loads. Chapter 4 presents facility modifications that may be suitable for implementation to assist in plant optimization efforts.

The intended users of this manual are owners, designers, and others associated with the responsibility of achieving compliance or more reliable performance from their existing facilities. The manual provides procedures for: 1) conducting performance evaluations, 2) implementing performance improvement activities, and 3) selecting facility modifications for secondary treatment plants that have identified design limitations. Relative to implementing facility modifications (i.e., Chapter 4), only general design criteria and guidelines are discussed. The manual user will need to refer to the specific references for the more detailed design information.

The manual focuses on conventional secondary treatment facilities which are broadly categorized as suspended growth facilities (e.g., activated sludge), fixed film facilities (e.g., trickling filter), and stabilization ponds.

As defined by the EPA, a secondary treatment plant is a facility designed to provide an effluent with monthly average BOD_5 and TSS concentrations of 30 mg/L. Stabilization pond modifications described in the manual are those that allow ponds to meet the relaxed standards for facilities less than 88 L/s (2 mgd) capacity (i.e., typically 30 mg/L BOD_5 and 75 mg/L TSS).

Preliminary and primary treatment and sludge treatment processes are presented, but only from the perspective of their impact on achieving desired secondary effluent quality. Nutrient removal facilities are specifically excluded from this manual except where aspects of these processes (i.e., oxygen requirements for nitrification) directly impact secondary treatment processes. Innovative/alternative (I/A) technologies are presented, where applicable, with respect to modifying the capabilities of existing conventional facilities. However, facility modifications directed toward improving performance of innovative/alternative technologies are beyond the scope of the manual. Also, land treatment technologies are not addressed in this manual. Readers interested in this technology are directed to other sources (5,6).

1.4 Using the Manual

This manual represents an expanded update of the EPA Handbook *Improving POTW Performance Using the Composite Correction Program Approach* (7) coupled with additional materials which address methods of selecting and implementing facility modifications. The manual is intended to be used in whole or in part to pursue improved performance with existing facilities.

Text of the manual closely parallels the major steps depicted in Figure 1-1. Chapter 2 discusses an evaluation approach to identify reasons for non-compliance and to assess the suitability of existing facilities for improved performance. The procedure described is called a CPE. At non-complying facilities, this (or similar) evaluation procedure should be implemented before a decision is made to pursue the next phase of performance improvement.

Chapter 3 discusses the CCP approach which details methods of optimizing existing facilities without major capital expenditures. Procedures to address design, operation, maintenance, and administrative factors limiting performance are outlined. Implementation of a CCP ensures optimization of existing facilities, and, if compliance is not achieved, the design factors limiting performance are identified.

Chapter 4 has been added to the manual to provide the reader with a more detailed description of facility modifications that can result in improved performance. This portion of the manual can be used in conjunction with the CPE/CCP steps outlined in Chapters 2 and 3 or it can be used alone if the reader has already identified that a facility modification is necessary to achieve desired effluent quality. In both cases the user of this portion of the manual must have already established the design factors or deficiencies limiting performance of the treatment facility. Chapter 4 utilizes a tabular format to list design factors that can potentially limit compliance of major unit processes, describes briefly the manner in which compliance is affected, and directs the reader to those sections of the chapter where specific information regarding suggested facility modifications are discussed.

1.5 References

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4. 1984 National Municipal Policy. *Federal Register*, January 30, 1984.

5. *Process Design Manual: Land Treatment of Municipal Wastewater*. EPA-625/1-81-013, U.S. Environmental Protection Agency, Cincinnati, OH, 1981.

6. *Process Design Manual: Land Treatment of Municipal Wastewater - Supplement on Rapid Infiltration and Overland Flow*. EPA-625/1-81-013a, U.S. Environmental Protection Agency, Cincinnati, OH, 1984.

7. *Handbook: Improving POTW Performance Using the Composite Correction Program Approach*. EPA-625/6-84-008, U.S. Environmental Protection Agency, Cincinnati, OH, 1984.

Chapter 2

Comprehensive Performance Evaluations

2.1 Introduction

This chapter provides information on the evaluation phase of a two-step process to economically improve the performance of existing publicly owned treatment works (POTWs). The evaluation phase, called a Comprehensive Performance Evaluation (CPE), is a thorough review and analysis of a POTW's design capabilities and associated administrative, operational, and maintenance practices. It is conducted to provide information for POTW administrators to make decisions regarding efforts necessary to improve performance. The primary objective is to determine if significant improvements in treatment can be achieved without major capital expenditures. This objective is accomplished by assessing the capability of major unit processes and by identifying and prioritizing those factors that limit performance and which can be corrected to improve performance.

The second step of the process is called a Composite Correction Program (CCP) and represents the performance improvement phase. It is a systematic approach to eliminating those factors that inhibit performance in existing POTWs. A CCP focuses on optimizing the capability of existing facilities to perform better. This phase is described in Chapter 3.

It is assumed that POTW owners and administrators have already recognized a need to improve the performance of their wastewater treatment facilities and will use this manual to economically accomplish the required wastewater effluent quality.

2.2 Approach to Conducting CPEs

2.2.1 Methodology

A CPE involves several activities: evaluation of the major unit processes; identification of performance-limiting factors; prioritization of performance-limiting factors; assessment of approach to improve performance; and reporting results of the evaluation. Although these are distinct activities, some are conducted concurrently with others. For example, evaluation of the major unit processes and identification of performance-limiting factors are generally undertaken at the same time.

Although this chapter presents all the information required to conduct a CPE, many references are available on techniques for evaluation of treatment plant performance, reliability, etc. (1-14). It is recommended that these references be consulted for further specifics on the subject.

2.2.1.1 Evaluation of Major Unit Processes

Major unit processes are evaluated to assess their potential to achieve desired performance levels. If the CPE indicates that the major unit processes are adequate or potentially adequate, a major plant expansion or upgrade may not be necessary and a properly conducted CCP should be implemented to achieve optimum performance. If, on the other hand, the CPE shows that major unit processes are inadequate, owners should consider modification of these processes as the focus for achieving desired performance.

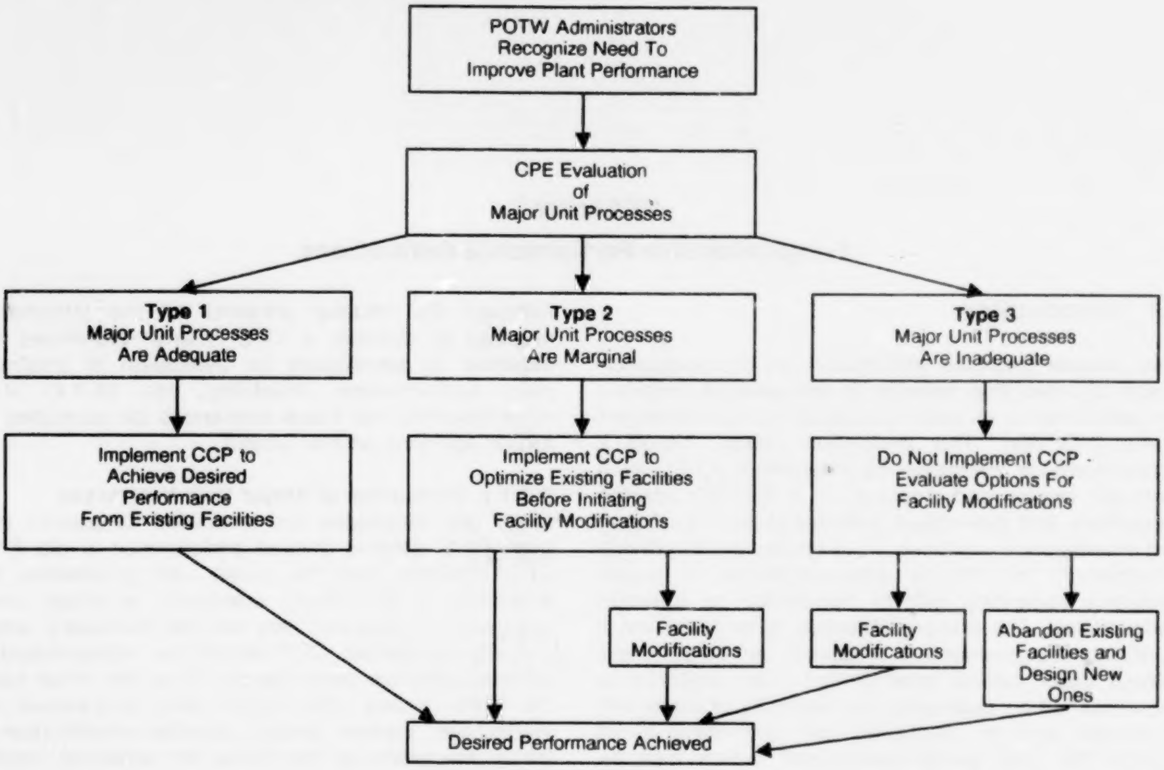
Results of evaluation of major unit processes can be summarized by categorization of plant type, as illustrated in Figure 2-1.

Type 1 plants are those POTWs where a CPE shows that current performance difficulties are not caused by limitations in the size or capabilities of the existing major unit processes. In these cases, the major problems are related to plant operation, maintenance, or administration, or to problems that can be corrected with only minor facility modifications. POTWs that fall into this category are most likely to achieve desired performance through the implementation of a nonconstruction-oriented CCP.

Identification of a POTW as Type 2 represents a situation where the marginal capacity of major unit processes will potentially prohibit the ability to achieve the desired performance level. For Type 2 facilities, implementation of a CCP will lead to improved performance but may not achieve required performance levels without facility modifications to the major treatment units.

A Type 3 plant is one in which the existing major unit processes are inadequate. Although other limiting factors may exist, such as the operators' process control capability or the administration's unfamiliarity

Figure 2-1 CPE/CCP schematic of activities.



POTW Administrators Recognize Need To Improve Plant Performance
CPE Evaluation of Major Unit Processes
Type 1 Major Unit Processes Are Adequate
Type 2 Major Unit Processes Are Marginal
Type 3 Major Unit Processes Are Inadequate
Implement CCP to Achieve Desired Performance From Existing Facilities
Implement CCP to Optimize Existing Facilities Before Initiating Facility Modifications
Do Not Implement CCP - Evaluate Options For Facility Modifications
Facility Modifications
Facility Modifications
Abandon Existing Facilities and Design New Ones
Desired Performance Achieved

with plant needs, performance cannot be expected to improve significantly until physical limitations of major unit processes are eliminated. In this case, implementation of a nonconstruction-oriented CCP may only be of limited value and is not recommended. Owners with a Type 3 plant could meet their performance requirements by pursuing modifications of existing wastewater treatment facilities. However, depending on future waste loads, more detailed study of treatment alternatives and financing mechanisms may be warranted. CPEs that identify Type 3 facilities are still of benefit to POTW administrators in that the need for construction is clearly defined for facility owners. Additionally, the CPE provides an understanding of the capabilities and weaknesses of existing operation and maintenance practices and administrative policies. POTW owners can use this information to evaluate use of existing facilities as part of any plant modification and as a guideline for optimizing operational, maintenance, and administrative practices.

2.2.1.2 Identification of Performance-Limiting Factors

Whereas the evaluation of major unit processes in a plant is used to broadly categorize performance potential by assessing only physical facilities, the identification of performance-limiting factors focuses on one facility and the factors unique to that facility. To assist in this identification, a list of 70 different factors that could potentially limit a POTW's performance is provided in Appendix A (1). These factors are divided into the categories of administration, maintenance, design, and operation. Suggested definitions of each factor are also provided. This list was developed as a result of many plant studies and is provided for convenience and reference. If alternate names or definitions provide a clearer understanding to those involved in conducting a CPE, they should be used. If different terms are used, each factor should be defined and these definitions should be readily available to those conducting the CPE and those interpreting the results. Note that the list includes factors on capacity of major unit processes. If the evaluation of major unit processes results in a Type 2 or 3 classification, these same limitations should be documented in the list of factors limiting the POTW's performance.

Completing the identification of factors is difficult in that true problems in a POTW are often masked. This concept is illustrated in the following discussion.

> A contact stabilization plant was routinely losing sludge solids over the final clarifier weirs, through the chlorine contact tank, and to the receiving stream, resulting in noncompliance with the plant's permit. Initial observations could lead to the

conclusion that the plant had an inadequately sized final clarifier. However, further investigation indicated that the solids loss was a result of the operator's practice of routinely wasting less sludge than was produced. It was determined that increased operator time and additional monitoring equipment would be required to properly control the sludge mass. It was further determined that the digester was undersized and would not provide adequate residence time for complete digestion of the waste activated sludge.

The most obvious problem is the operator's lack of knowledge of how to apply the concept of sludge mass control. The needed laboratory equipment was within the approved budget for the facility and therefore was not assessed as a major problem. Plant administrators indicated that they could not afford additional operator time. This administrative policy was a significant factor limiting performance. The undersized digester was a less significant problem in this case because unlimited cropland for disposal of partially digested sludge was available. (Note: Disposal of partially digested sludge on cropland can no longer be considered a permanent solution since promulgation of Federal regulations for land disposal of POTW sludges). It was concluded that four factors contributed to the solids loss that caused poor plant effluent quality:

1. Inadequate operator knowledge to apply the concept of sludge mass control.
2. Restrictive administrative policy that prohibited needed operator time.
3. Inadequate test equipment.
4. Inadequate digester capacity.

The above discussion illustrates that a comprehensive analysis of a performance problem is essential to identify the true performance-limiting factors. If the initial obvious problem of lack of clarifier capacity had been identified, improper corrective actions and unnecessary expenditures of funds would likely have occurred.

It is emphasized that the purpose of identifying performance-limiting factors is to identify, as accurately as possible, causes of poor performance unique to a particular plant. Observation that a factor does not meet the "industry standard" does not necessarily constitute cause for identifying that factor as limiting the POTW's performance. An actual link between poor plant performance and an identified factor must exist.

2.2.1.3 Prioritization of Performance-Limiting Factors

In almost all CPEs, several factors are identified as limiting performance. After these factors have been identified, they are prioritized as to their adverse effect on achieving desired plant performance. The purposes of this prioritization are to establish the sequence and/or emphasis of follow-up activities necessary to achieve compliance. If the highest ranking factors (i.e., those having the most negative impact on performance) are related to physical limitations in unit process capacity, initial corrective actions are directed toward defining plant modifications and obtaining administrative funding for their implementation. If the highest ranking factors are process control oriented, the initial emphasis of follow-up activities would be directed toward plant-specific operator training.

The prioritization of factors is accomplished by a two-step process. First, all factors that have been identified are individually assessed with regard to adverse impact on plant performance and assigned an "A," "B," or "C" rating (Table 2-1). The checklist of factors in Appendix A includes a column to enter this rating. Second, those factors receiving "A" or "B" ratings are listed in order of priority, since typically all "A" and "B" factors must be eliminated before a plant will achieve consistent desired performance.

Table 2-1. Classification System for Prioritizing Performance-Limiting Factors

Rating	Adverse Effect of Factor on Plant Performance
A	Major effect on long-term repetitive basis
B	Minimum effect on routine basis or major effect on a periodic basis
C	Minor effect

Factors that are assigned an "A" are the major problems that cause a performance deficiency. They should be the central focus of any subsequent program to improve plant performance. An example of an "A" factor would be "ultimate sludge disposal" facilities (e.g., drying beds) that are too small to allow routine wasting of sludge from an activated sludge POTW.

Factors are assigned a "B" if they fall in one of two categories:

1. Those that routinely contribute to poor plant performance but are not the major problems. An example would be a shortage of staff time to complete required process control testing in a small activated sludge plant where the underlying problem is that the operator does not understand how to run or interpret the tests or understand the need for a better testing program.
2. Those that cause a major degradation of plant performance, but only on a periodic basis. Typical examples are infiltration or inflow that cause periodic solids loss from final clarifiers, or marginal oxygen transfer capacity that causes an oxygen shortage only during the hottest month of the year.

Factors that receive a "C" rating can be shown to contribute to a performance problem, but their effect is minor. For example, if a critical process stream were accessible, but difficult to sample, it could indirectly contribute to poor performance by making process control testing less convenient and more time consuming. The problem would not be a major focus of a subsequent corrective program. As a comparison of the different ratings, the example "A" factor above ("ultimate sludge disposal") would receive a "B" rating if adequate drying bed capacity were available in the summer but winter weather inhibited drying bed use. The factor would receive a "C" rating if adequate drying bed capacity were available but cleaning the beds with a front loader has crushed several underdrain tiles.

In the illustration presented in Section 2.2.1.2, "inadequate operator knowledge to apply the concept of sludge mass control" is assigned an "A" because of its continuous detrimental effect on plant performance; "administrative policy" a "B" because of its routine effect; and "testing equipment" a "C" because its effect is only a minor contributing factor. "Inadequate digester size" is given a "B" because it made proper sludge mass control more difficult and labor intensive. It is not given an "A" because it did not limit performance in a major way since adequate sludge disposal capacity is available by utilizing nearby cropland.

During the conduct of a CPE, the factors that are not identified as performance limiting also provide very useful information for POTW owners. For example, in the illustration presented in Section 2.2.1.2, the clarifier was not identified as a performance-limiting factor. Since it was not identified, plant personnel do not need to focus on the clarifier as a problem. Typically 5 to 15 factors are identified during a CPE. The remaining 55 to 65 factors outlined in Appendix A that are not identified represent a significant finding and also a source of providing recognition to plant personnel for adequately addressing these sources of problems.

Once each identified factor is assessed individually and assigned an "A," "B," or "C" classification, those receiving "A" or "B" ratings are listed on a one-page summary sheet in order of priority. This requires that the evaluator assess all the "A" and "B" factors to determine the most serious cause of poor performance, second most serious, etc. A summary sheet for ranking the prioritized factors limiting plant performance in order of severity is presented in Appendix B. This process is effective in reducing the identified factors to a one-page summary and serves as a valuable reference for the next step of the CPE: assessing ability to improve plant performance.

All factors limiting facility performance typically cannot be, nor are they intended to be, identified during the CPE phase. It is often necessary to later modify the original corrective steps and requirements as new or additional information becomes available during the conduct of a performance improvement (CCP) phase. This concept is illustrated by the following:

> A CPE conducted at an activated sludge plant identified the major performance-limiting factors as;
>
> 1. Inadequate operator understanding to make process adjustments to control sludge settling characteristics ("A").
>
> 2. Inadequate staffing to make operational adjustments ("B").
>
> 3. Inadequate maintenance program to keep equipment functioning continuously ("C").
>
> Based on these factors, a CCP was implemented to improve performance of the existing facilities. It was decided that this plant could perform best when the activated sludge settling rate was relatively slow. The plant operator's understanding was improved through training, and he became capable of making process control adjustments to achieve the desired slower sludge settling rate. Once the desired slower sludge settling rate was achieved, poor clarifier performance was observed and effluent quality deteriorated. Further investigation indicated that modifications made a year earlier to the clarifier inlet baffles were allowing short-circuiting to occur. This short-circuiting only became apparent after the slower settling sludge solids predominated in the system. These baffle modifications were reassessed and changed to reduce short-circuiting, and effluent quality improved dramatically.

In this illustration, a minor design modification was determined to be a performance-limiting factor. This factor was not identified in the original CPE. An awareness that it may not be possible to identify all performance-limiting factors in the CPE, as well as an awareness that the performance improvement phase allows further definition and identification of factors during its implementation, is an important aspect of understanding the approach to conducting a CPE.

2.2.1.4 Assessing Approach to Improve Performance

All performance-limiting factors can be eliminated. Therefore, it is necessary to specifically assess the ability to achieve improved performance in each POTW. If performance improvement efforts are restricted to existing facilities, then a CCP with facility modifications or facility modifications can be employed to eliminate identified performance-limiting factors (Figure 2-1). Another option is to abandon the existing plant and design new facilities.

An assessment of the list of prioritized factors helps assure that all factors can realistically be addressed given the unique set of factors noted at the facility being evaluated. Often there are practical reasons why a factor cannot be addressed in a straightforward manner. Examples of factors that may not be feasible to address directly are replacement of key personnel, required increases in funding, or training of uncooperative owners or administrators to support POTW needs. As such, alternative solutions or combinations of corrective actions that can effectively address the problem may have to be developed. For example, an activated sludge secondary clarifier may be improved by installing baffles to decrease short-circuiting, by utilizing partial flow equalization to reduce hydraulic peaks, or by switching to other activated sludge modes to modify sludge settling characteristics. Often a combination of these corrective actions would be appropriate.

Proper interpretation of the CPE findings is necessary to provide the basis for recommendations of which alternatives to pursue for the performance improvement phase. It is at this assessment phase that the maximum application of the evaluator's judgment and experience is required.

2.2.1.5 CPE Report

The results of a CPE should be summarized in a brief, written report to provide guidance for facility owners and administrators. An example is included in Appendix C. A typical CPE report is 8-12 pages in length and includes the following topics:

- Facility background
- Major process evaluation
- Performance-limiting factors
- Performance improvement activities
- Costs

A CPE report should not provide a list of specific recommendations for correcting individual performance-limiting factors. This often leads to a piecemeal approach to corrective actions where the goal of improved performance is not met. For Type 1 and 2 plants, the necessity of comprehensively addressing the combination of factors identified by the CPE through the implementation of a CCP should be stressed. For Type 3 plants, a recommendation for a facility modification or a more detailed study to support the anticipated upgrade may be warranted.

2.3 How to Conduct a CPE

2.3.1 Initial Activities

To determine the magnitude of the fieldwork required, and to make the on-site activities most productive, specific initial information should be gathered. This information includes basic data on the POTW and sources for any needed additional information. If a person associated directly with the POTW is the evaluator conducting the CPE, some of the steps may not be necessary.

2.3.1.1 Personnel

The evaluator should obtain the names of those persons associated with the POTW who will be the primary sources of information for the CPE. The POTW superintendent, manager, or other person in charge of the wastewater treatment facility should be identified. If different persons are responsible for plant maintenance and process control, they should also be identified.

The person most knowledgeable about the details of the POTW budget should be identified by name, position, and physical location. A one- to two-hour meeting with this person during the fieldwork will have to be scheduled to obtain a copy of the budget and discuss it. In many small communities, this person is most often the city clerk; in larger communities, the utilities director or wastewater superintendent can usually provide the best information on the budget.

Key administrative personnel should also be identified. In many small communities or sanitation districts, an operator or plant superintendent may report directly to the elected governing administrative body, usually the city council or district board. In larger communities, the key administrative person is often the director of public works, city manager, or other non-elected administrator. In all cases, the administrator(s) who has the authority to effect a change in policy or budget for the POTW should be identified.

If a consulting engineer is currently involved with the POTW, that individual should be informed of the CPE and be provided a copy of the final report for comment. Normally, the consulting engineer will not be directly involved in conduct of the CPE. An exception may occur if there is an area of the evaluation that could be supplemented by the expertise available through the consultant.

2.3.1.2 Wastewater Treatment Plant

The initial information outlined in Appendix D (Form D-1) can be used to estimate field time required. The plant superintendent and/or chief operator typically would be the contact for this information. This information should be collected bearing in mind that some of the data may later be found to be inaccurate. As such, the data that a chief operator can provide from memory or from a readily available reference are sufficient at this time.

Irregularities that may warrant special consideration when planning or conducting the fieldwork should be identified, and more specific questions should be asked to define the potential effect on the evaluation. Frequently occurring irregularities include: major process or pieces of equipment out of service; key persons on vacation or scheduled for other priority work; and new or uncommon treatment processes.

An out-of-service single trickling filter, aeration basin, or final clarifier will probably necessitate postponing fieldwork in small plants. In plants with duplicate unit processes, a CPE can be conducted with one unit out of service if the results of the evaluation are needed before normal operation can be resumed.

2.3.1.3 Scheduling

Interviews of personnel associated with the wastewater treatment facilities are a key component of conducting a CPE. As such, the major criterion for scheduling the time for a CPE should be local personnel availability. Usually, one-half to two-thirds of the time scheduled for fieldwork will require the availability and help of these persons.

Scheduling should be coordinated with the availability of at least the major process control decision-maker, the major administrative decision-maker, and the person most knowledgeable of the plant budget. A commitment of time from these key persons is essential to the successful conduct of a CPE. It may also be beneficial to inform State and Federal regulatory personnel of the CPE schedule. Responsibility for this task should be clearly identified between the evaluator and local personnel during the scheduling of activities.

During the fieldwork, the process control decision-maker should be prepared to devote at least half of his/her time to the evaluation. The administrative decision-maker should be available for one hour for a kickoff meeting, several hours for reviewing the budget, another several hours for an interview concerning plant administration issues, and one to two hours for a summary meeting.

2.3.2 *Data Collection*

Onsite CPE activities are largely devoted to collection and evaluation of data. As a courtesy to the facility owner, and to promote efficient data collection, the fieldwork is initiated with a kickoff meeting and a plant tour. These activities are followed by a period of time where a large amount of detailed data on the POTW are gathered and analyzed.

2.3.2.1 Kickoff Meeting

A short meeting between key POTW personnel (including key administrators) and the evaluator should be held to initiate the fieldwork. The major purposes of this meeting are to explain and gain support for the CPE effort, to coordinate and establish the schedule, and to initiate the administrative evaluation activities. The objectives of the CPE should be presented along with the proposed activities. Specific meeting times for interviews with non-plant and plant personnel should be scheduled. Information and resource requirements should be spelled out. Specific items that are required and may not be readily available are: budget information to provide a complete overview of costs associated with wastewater treatment; schedule of sewer use and tap charges; discharge permit (NPDES) for the POTW; historical monitoring data (1 year); utility bills (1 year); sewer use ordinance (if applicable); and any facility plans or other engineering studies completed on the existing facility.

Administrative factors that may affect plant performance should be noted during this meeting, such as the priority put on permit compliance, familiarity with plant needs, communication between administration and plant staff, and policies on plant funding. These initial perceptions often prove valuable when formally evaluating administrative factors later in the CPE effort.

2.3.2.2 Plant Tour

A plant tour should follow the kickoff meeting. The objectives of the tour are to familiarize the evaluator with the physical plant, make a preliminary assessment of design operational flexibility of the existing unit processes, and provide an initial basis for discussions on performance, process control, and maintenance. A walk-through tour following the flow of wastewater is suggested. It is then appropriate to tour the sludge treatment and disposal facilities, followed by the support facilities such as maintenance areas and laboratories. The evaluator should note the sampling points established throughout the plant for both process control and compliance monitoring. Suggestions to help the evaluator meet the objectives of the plant tour are provided in the following sections.

a. Preliminary Treatment

Major components of preliminary treatment typically include coarse screening or comminution, grit removal, and flow measurement.

Although inadequate screening rarely has a direct effect on plant performance, it can become a significant factor. For example, if surface mechanical aerators must be shut down twice a day to remove rags in an activated sludge plant with marginal oxygen transfer capacity, screening could be a major limitation. Indications of screening problems are:

- Plugging (with rags) of raw sewage or primary sludge pumps
- Plugging of trickling filter distributors
- Rag buildup on surface mechanical aerators or submerged diffusers
- Plugging of activated sludge return pumps where primary clarifiers are not used

Grit removal generally only has an indirect effect on plant performance. For example, inadequate grit removal can cause excessive wear on pumps or other downstream and sludge processing equipment, resulting in excessive downtime which could impact plant performance and reliability.

Wastewater flow measurement facilities are important to accurately establish plant loadings. The plant tour should be used to observe the primary measuring devices and to ask several questions regarding plant flows. If flow is turbulent or non-symmetrical through flumes and over flow measurement weirs, the flow records are immediately questionable. If flow is non-turbulent and symmetrical, there is a good chance the flow measurement device is sufficiently accurate, provided the flow recorder and totalizer prove to be properly calibrated. The evaluator should always plan to verify the accuracy of flow measurement during the fieldwork.

Sources of wastewater and the nature of the waste contributions should initially be discussed when observing preliminary treatment facilities. Impacts of infiltration and inflow on plant flows should also be discussed.

b. Primary Clarification
The value of primary clarification in relation to overall plant performance is in decreasing the load on subsequent secondary treatment processes. As such, the evaluator should determine what performance monitoring of the primary processes is conducted. At a minimum, sufficient data to calculate average BOD_5 loadings on the secondary portion of the plant should be available. The areas of major concern that should be discussed during the tour are flexibility available for changing operational functions and clarifier performance.

The major operational variable that affects primary clarifier performance is sludge removal. The evaluator should discuss the process control method used to adjust sludge withdrawal. In general, primary clarifiers work best with a minimum of sludge in the clarifier (low sludge detention times and low blanket level). The practical limit for minimizing the sludge in the clarifier is when the sludge becomes too thin (i.e., too much water) such that it adversely affects the capacity and/or performance of the sludge handling facilities. A primary sludge concentration of less than 3 percent total solids often indicates there is opportunity for improved sludge handling facilities performance with decreased sludge pumping. On the other hand, a primary sludge concentration of greater than 6 percent total solids can be an indication that primary clarifier performance may be improved by increased sludge pumping. The operational approach used to improve primary clarifier performance must be balanced with the capacity and performance requirements of the sludge handling processes.

The surface overflow rate (SOR), which is the daily average flow divided by clarifier surface area (CSA), can be used as an indicator to estimate the performance that can be expected from a primary clarifier handling typical domestic wastewater. A clarifier operating at an SOR of less than 24 $m^3/m^2/d$ (600 gpd/sq ft) will typically remove 35-45 percent of the BOD_5 in domestic wastewater. A clarifier operating at an SOR of 24-40 $m^3/m^2/d$ (600-1,000 gpd/sq ft) will typically remove 25-35 percent of the BOD_5.

c. Aerator
The term "aerator" is used in this manual to describe the unit process that provides the conversion of dissolved and suspended organic matter to settleable microorganisms. Examples of an aerator are: aeration basin, trickling filter, and rotating biological contactor (RBC). The aerator represents a critical process in the wastewater flow stream in determining overall plant performance capability. During the plant tour, the evaluator should determine if current operating conditions represent normal conditions and inquire about what operational flexibility is available. For example: Can trickling filters be run in parallel as well as series? Can recirculation be provided around the filter only? Can aeration basins be operated in a step loading mode as well as a plug flow mode?

d. Secondary Clarification
In all biological wastewater treatment plants, the main function of secondary clarification is to separate the sludge solids from the treated wastewater. Another purpose is to thicken the sludge before removal from the clarifier. Characteristics that should be noted on the plant tour are configuration, depth, and operational flexibility.

The evaluator should note the general configuration of the clarifier, including shape, sludge removal mechanism, and weir and launder arrangement. A circular clarifier with a "donut" launder located several feet from the clarifier wall and a siphon-type, rapid withdrawal sludge collector often provides satisfactory performance. A long, narrow, shallow rectangular clarifier with effluent weirs only at the end often provides marginal solids separation and thickening capability. Clarifiers with a depth of less than 3 m (10 ft) provide limited sludge storage and thickening capability and create concerns about capacity, especially in activated sludge plants.

The SOR can be used to roughly estimate final clarifier performance capability. A SOR, based on average daily flow less than 24 $m^3/m^2/d$ (600 gpd/sq ft), typically can be operated to achieve desired performance. A significantly higher SOR would mean that other processes would have to be fairly conservative to make the system perform adequately.

When touring activated sludge facilities, the evaluator should become familiar with operation and flexibility of the return sludge scheme: how sludge is withdrawn from the clarifier; ability to operate at higher or lower recycle rates; availability of return sludge flow measurement; and flexibility to direct return sludge to different aeration basins or points in the basins.

e. Disinfection
The evaluator should tour disinfection facilities to become familiar with the process and equipment available and because inspection of disinfection facilities often provides insight into performance of the secondary treatment process. Where disinfection is required, nearly all POTWs use chlorine as the disinfectant and incorporate a chlorine contact basin of sufficient size to provide 10 minutes to 2 hours of contact time.

Poorly performing biological wastewater treatment facilities periodically lose sludge solids over the final clarifier weirs. Chlorine contact basins generally will capture a portion of these solids. If more than 5-10 cm (2-4 in) of sludge has built up on the bottom of the basin, there is a good chance that significant solids loss is occurring from the secondary clarifier.

f. Sludge Handling Capability
During the tour of sludge handling facilities, the evaluator should become familiar with primary and secondary sludge management practices, including: 1) methods used to determine waste sludge quantities; 2) equipment used to thicken, stabilize, and dewater sludge; and 3) available options for final disposal and reuse. The evaluator's major concern with sludge handling facilities is identifying any potential "bottlenecks" and possible alternatives if problems that may limit performance are indicated.

All recycle streams should be identified during the tour and the plant personnel should be questioned regarding the availability of data concerning each stream's volume and strength. Return supernatant streams from anaerobic digesters and heat treatment conditioning processes are the most common return streams that cause performance problems. Supernatant from aerobic digesters and filtrate from dewatering operations typically have a lesser impact on plant performance.

g. Stabilization ponds
Municipal wastewater stabilization ponds are typically classified as facultative or aerated, depending on the method used to provide oxygen transfer in the facility. Characteristics that should be noted include the number of ponds, type of aeration and mixing, and flexibility in flow patterns and discharge structures. System flexibility should investigated (i.e., Can the ponds be operated in both series and parallel? Is recirculation flexibility provided between ponds? Does the discharge structure for a pond allow draw-off at various levels?).

h. Laboratory
The laboratory facilities should be included as part of the plant tour. Performance monitoring, process control testing, and quality control procedures should be discussed with laboratory personnel. Available analytical capability should also be noted. Sampling and analytical support are often essential parts of the evaluation effort and the evaluator should determine what level of support is available from the laboratory during the CPE.

i. Maintenance Facilities
Maintenance facilities should be included as part of the plant tour. Tools; spare parts availability and storage, filing systems for equipment catalogs, general plant appearance, and condition of equipment should be observed during the tour. Questions on the preventive maintenance program, including methods of initiating work (e.g., work orders), are appropriate.

2.3.2.3 Detailed Data Gathering
Following the plant tour, a major effort is initiated to collect all data necessary to assess the performance potential of the existing facilities. This data collection effort may require two or three persons for 3-7 days in a larger plant, and one or two persons for 1-2 days in a smaller plant.

Information is collected to document past performance, process design, maintenance, management, budget, process control, and administrative policies. Collecting information for many of these items requires the assistance of POTW and other personnel. As such, the data gathering should be scheduled around their availability. The time when key personnel are not available should be used to initially review documents such as O&M manuals and construction plans, to summarize notes and questions for POTW personnel, and to check completeness of data collection.

The forms in Appendix D have proven to be valuable working guidelines for the data collection effort (1). Items covered by these forms are listed below:

- Preliminary Plant Information, Form D-1
- Administration Data, Form D-2
- Design Data, Form D-3
- Operations Data, Form D-4
- Maintenance Data, Form D-5
- Performance Data, Form D-6
- Interview Data, Form D-7

When collecting information using these forms, the evaluator should be aware that the data are to be used to evaluate the performance capability of the existing POTW. The evaluator should continuously be asking "How does this affect plant performance?" If the area of inquiry is directly related to plant performance, such as a clarifier design or an administrative policy to cut electrical costs to an unreasonable level, the evaluator should spend sufficient time and effort to fully understand and define the effect on plant performance. If the area of inquiry is not directly related to plant performance, such as the appearance of the grounds, the condition should be noted and efforts directed toward areas that specifically impact performance.

Completion of Form D-3 requires that values be selected to represent current plant hydraulic and BOD_5 loadings. Typically, data for the most recent 12 months are used.

2.3.3 Evaluation of Major Unit Processes

Early in the on-site activities, an evaluation of the POTW's major unit processes is conducted to determine the performance potential of existing facilities at current loadings (i.e., define the facility as Type 1, 2, or 3 as described in Section 2.2). The three unit processes whose capabilities most frequently affect biological wastewater treatment plant performance are: the aerator, the secondary clarifier, and the sludge handling system (1,15,16).

A point system is used to quantify the evaluation of these three basic unit processes. Key loading and process parameters are calculated and results for each parameter assigned points by comparison with standard tables. Subsequently, each of the three major unit processes receives a total score by adding together the value of the points assigned the loading and process parameters. The totals are then compared with standards to assess whether a Type 1, 2, or 3 capability is indicated for that unit process (see Figure 2-1). The overall plant type is determined by the "weakest link" among the three major process areas. It must be remembered in using this point system that this simplification can provide valuable assistance but cannot replace the overall judgment and experience of the evaluator.

2.3.3.1 Suspended Growth Major Unit Processes

Suspended growth facilities include those plants using variations of the activated sludge process. The three significant unit processes within these types of facilities that determine capacity and performance are the aeration basin, secondary clarifier, and sludge handling system.

a. Aeration Basin

Parameters that are used for scoring the capability of an aeration basin are: hydraulic detention time, BOD_5 loading, and oxygen availability. The point system for scoring these parameters is presented in Table 2-2. To obtain the necessary parameters, information is required on wastewater flow to the aeration basin, aeration basin BOD_5 loading, aeration basin liquid volume, and oxygen transfer capacity.

Table 2-2. Parameters for Scoring Capability of Aeration Basins in Suspended Growth POTWs*

Current Operating Condition	Points	Points
Hydraulic Detention Time, hr:		
24	10 (max,)	
10	6	
5	0	
3	-6	
BOD_5 Loading, kg/m^3/d (lb/d/1,000 cu ft):		
0.24 (15)	10 (max.)	
0.40 (25)	6	
0.80 (50)	0	
1.28 (80)	-6	
Oxygen Availability, kg O_2/kg BOD_5 applied:	w/ nitrification	w/o nitrification
2.0	10 (max.)	10 (max.)
1.5	5	10 (max)
1.2	0	5
1.0	-5	0
0.8	-10	-5
0.6	-10	-10

* Interpolate to nearest whole number between loadings listed.

Oxygen transfer capacity is usually the most difficult information to obtain if the original engineering data are not available or if there is some reason to question the original design data based on current conditions. Generally, the evaluation proceeds by using available data on oxygen transfer capacity and assuming it is correct unless the transfer capacity appears to be marginal. If oxygen transfer capacity appears marginal, further investigation is warranted. Any of the following conditions would lead an evaluator to suspect marginal oxygen transfer:

- Difficulty in maintaining minimum desired dissolved oxygen concentrations in the aeration basin
- Continuous operation of all blowers or all aerators set at high speed
- Design data showing less than 1.2 kg oxygen transfer capacity per kg actual BOD_5 load

If design oxygen transfer numbers are unavailable or are believed suspect, oxygen transfer rates presented in Table 2-3 can be used to estimate oxygen transfer capacities.

Typically, the oxygen transfer efficiency (percent) is used when evaluating different diffused air systems, and oxygen transfer rate (lb O_2/hp-hr) is used when evaluating surface mechanical aerators. The evaluation of both diffused air and surface mechanical aerators is described in more detail below.

Table 2-3. Typical Clean Water Standard Oxygen Transfer Values

System	Oxygen Transfer Efficiency[a]	Oxygen Transfer Rate[b]
	percent	lb/wire hp-hr
Fine bubble diffusers, total floor coverage	28-32	6.0-6.5
Fine bubble diffusers, side wall installation	18-20	3.5-4.5
Jet aerators (fine bubble)	18-25	3.0-3.5
Static aerators (medium-size bubble)	10-12	2.3-2.8
Mechanical surface aerators	-	2.5-3.5
Coarse bubble diffusers wide band pattern	8-12	2.0-3.0
Coarse bubble diffusers, narrow band pattern	6-8	1.5-2.0

[a] at 15 feet submergence.
[b] 1 lb/hp-hr = 0.61 kg/kW-hr.

When evaluating oxygen transfer capability of diffused aeration systems it is necessary to assess the capacity of the aeration blowers and the standard transfer efficiency of the diffusers. This information is often available from O&M manuals, specifications, and manufacturers literature. If questionable information is available, typical values for various systems are shown in Table 2-3. The blower capacity and diffuser transfer efficiency can then be utilized to determine the amount of oxygen (lb/d) that can be transferred into the wastewater by the existing aeration system.

To determine the aeration system oxygen transfer in lb/day, the diffuser standard transfer efficiency or standard oxygen transfer rate at standard conditions (14.7 psia, 20°C, and clean water) must be converted to transfer efficiency at actual site conditions including adjustments for site elevation, wastewater temperature, and wastewater characteristics. The procedure to convert standard oxygen transfer rates to actual oxygen transfer rates is presented in Appendix E.

In addition, blower capacity must be determined in standard cubic feet per minute (SCFM) to determine the mass of air/oxygen that the blowers are capable of discharging. There is not a standard method of presenting blower output. Some manufacturers provide the blower rating in standard cubic feet per minute (SCFM), which is a term that describes airflow at standard conditions of 14.7 psia and 20°C. It is noted that different air temperatures, such as 70°F, are used by other manufacturers to describe standard conditions. Also, the blower output rating is often presented in terms of ICFM (inlet cfm) or ACFM (actual cfm), which is CFM at site conditions. ICFM, ACFM, or SCFM at standard conditions other than the conditions chosen for the evaluation must be converted to SCFM. The procedure to convert ICFM or ACFM to SCFM for the standard condition of 14.7 psia, 20°C and clean water, is presented in Appendix E.

Utilization of the procedures presented in Appendix E to calculate the oxygen transfer capability of a diffused air system is shown in the following example.

In Plant A there are four centrifugal blowers, each with a capacity of 1,550 acfm. Three are utilized, with one as standby. The standard oxygen transfer efficiency (SOTE) or efficiency of the coarse bubble diffusers is 12 percent at 15-ft water depth based on manufacturer's data. Plant A is located at 2,750 feet above sea level.

1. Convert SOTE = 12 percent to AOTE using:

$$\text{AOTE} = (\text{SOTE})\,\alpha \left[\frac{\beta\, C_{sw} - C_L}{C_s} \right] \theta^{T-20}$$

Where,

AOTE = actual oxygen transfer efficiency at site conditions, percent.
SOTE = standard oxygen transfer efficiency at standard conditions in clean water, percent.
α = 0.85 for coarse bubble diffuser, from Table E-1.
β = 0.95 for domestic wastewater.
θ = 1.024
C_s = 9.17 mg/L oxygen saturation at standard temperature and pressure.
C_{sw} = $C_{14.7}$ (P/14.7), mg/L

Assume maximum summer wastewater temperature = 25°C at Plant A. From Table E-2, $C_{14.7} = 8.38$ mg/L @ 25°C. From Figure E-1, P = 13.25 psia @ 2,750 ft above mean sea level. A potential depth correction can be applied to this term, as noted in Appendix E. However, to be more conservative in the evaluation, utilize atmospheric pressure:

$$C_{sw} = 8.38\ [13.25/14.7) = 7.55\ \text{mg/L}$$

C_L = 2.0 mg/L (mixed liquor DO concentration)

$$\text{AOTE} = \{(0.12)(0.85)\ [(0.95)(7.55)-2]\ 1.024^{25-20}\} \div 9.17$$

$$\text{AOTE} = 6.5 \text{ percent}$$

2. Convert blower output of 1,550 acfm to scfm:

$$\text{acfm} = \text{scfm}\ (T_a/T_s)(P_s/P_a)$$

Where,

acfm = 1,550 cfm.

T_a = 100°F + 460°F = 560°R (temperature at which manufacturer rated blowers).
T_s = 68°F + 460°F = 528°R (standard temperature).
P_s = 14.7 psia (standard pressure).
P_a = 13.25 psia (pressure @ 2,750 ft above mean sea level).

scfm = (1,550) (528/560) (13.25/14.7) = 1,317 cfm

3. Calculate lb O_2/d from 3 blowers using diffuser actual oxygen transfer efficiency of 6.5 percent and blower capacity of 1,317 cfm:

Peak air flow = 3 x 1,317 = 3,951 scfm

lb O_2/d = (scfm)(1,440 min/d)(23.2 lb O_2/100 lb air) x (0.075 lb air/cu ft air)(AOTE)

= (3,951)(1,440)(23.2/100)(0.075)(6.5)

= 6,435 lb/d

4. Therefore, 3 blowers @ 1,317 cfm each will transfer 6,435 lb O_2/d. Compare the oxygen transfer capability with the BOD_5 loading applied to determine the lb O_2/lb BOD_5 that the diffused air system can provide.

When evaluating the oxygen transfer capability of a surface mechanical aeration system, the power usage of the motor (whp) and the oxygen transfer rate of the aerator (lb O_2/whp-hr) must be determined. Various techniques for estimating motor power usage based on actual power measurements are presented in Appendix F. If power measuring equipment is not available, wire horsepower may be estimated by assuming the motor is 90 percent efficient and the surface mechanical aerator gear box is 85 percent efficient. Using these estimates, the evaluator may assume that 75 (appropriately 0.9 x 0.85) percent of the motor horsepower (mhp) is being converted to oxygen transfer energy, or wire horsepower. For example, if a surface mechanical aerator motor is rated at 50 mhp, the wire horsepower could be estimated to be 0.75 x 50 = 37.5 whp. Actual power measurements should be taken if the oxygen transfer capability of the system determined by estimating wire horsepower appears inadequate.

The aerator oxygen transfer rate may be determined from the O&M manual, specifications, and equipment manufacturer's literature. If questionable information is available, a typical value for surface mechanical aeration systems can be found in Table 2-3. The standard oxygen transfer rate (SOTR) is typically provided and this must be converted to the actual oxygen transfer rate (AOTR) as shown in Appendix E. Utilization of the procedures presented in Appendices E and F to determine actual oxygen transfer rate and motor wire horsepower are presented in the following example.

In Plant B there are two 50-hp surface mechanical aerators. Both units are utilized. The SOTR is 3 lb O_2/whp-hr based on manufacturer's data. Plant B is located at 2,750 ft above sea level.

1. Convert SOTR = 3 lb O_2/whp-hr to AOTR using

$$AOTR = (SOTR)\,\alpha \left[\frac{\beta C_{sw} - C_L}{C_s} \right] \theta^{T-20}$$

Where,

AOTR = actual oxygen transfer rate at site conditions, percent.
SOTR = standard oxygen transfer rate at standard conditions in clean water, percent.
α = 0.90 for surface mechanical aerator, from Table E-1.
β = 0.95 for domestic wastewater.
θ = 1.024
C_s = 9.17 mg/L oxygen saturation at standard temperature and pressure.
C_{sw} = $C_{14.7}$ (P/14.7), mg/L

Assume maximum summer wastewater temperature = 25°C at Plant B. From Table E-2, $C_{14.7}$ = 8.38 mg/L @ 25°C. From Figure E-1, P = 13.25 psia @ 2,750 feet above mean sea level.

$$C_{sw} = 8.38\ [13.25/14.7) = 7.55 \text{ mg/L}$$

C_L = 2.0 mg/L (mixed liquor DO concentration)

$$AOTR = \{(3)(0.9)\ [(0.95)(7.55)-2]\ 1.024^{25-20}\} \div 9.17$$

$$AOTR = 1.7 \text{ lb } O_2\text{/whp-hr}$$

2. Determine surface mechanical motor power usage:

a. Determine whp of motor based on the assumption that whp is 75 percent of mhp.

whp = 0.75 (50 mhp) = 37.5 whp

b. Determine whp based on actual power measurements and assumption that power factor is 0.90, as shown in Appendix F.

Voltage measurement = 480 volts

Amperage measurement = 37.4 amps

kVA = (V) (A) $(3)^{1/2}$ ÷ 1,000 (3-phase power)
= (480) (37.4) $(3)^{1/2}$ ÷ 1,000 = 31.1kW

kW = kVA x PF = 31.1 (0.9) = 28 kW

whp = kW ÷ 0.746 = 28 ÷ 0.746 = 37.5 hp

Total whp = 2 motors x 37.5 whp = 75 whp

3. Determine oxygen transferred based on AOTR and whp:

O_2 transfer = (1.7 lb O_2/whp-hr) (75 whp) (24 hr/d)
= 3,060 lb O_2/d

4. Compare the oxygen transfer rate with the plant BOD_5 applied loading to determine the lb O_2/lb BOD_5 that the surface mechanical aeration system can provide.

Once data are available on wastewater flows, BOD_5 of influent to the aeration basin, aeration basin volume, and oxygen transfer capacity, the following calculations should be completed by the evaluator:

Aerator Hydraulic Detention Time =
Aeration Basin Vol. ÷ Peak Month ADWF

Peak month average daily wastewater flow is typically for the most recent 12 months. Peak month flow is used to ensure that the aerator is capable of meeting monthly average effluent requirements.

BOD_5 Loading =
BOD_5 Applied Loading ÷ Aeration Basin Volume

BOD_5 loading is typically the daily average value for the most recent 12 months. Peak value is not used since aerator capability is not as sensitive to "normal" BOD_5 loading variations.

Oxygen Availability =
Oxygen Transfer Capacity ÷ BOD_5 Applied Loading

When the above calculations have been completed for the subject POTW, the results are compared to the values given in Table 2-2 and appropriate points are assigned each parameter. If the parameters for the subject POTW fall between the values listed, interpolation is used to assign appropriate points.

b. Secondary Clarifiers

Parameters that are used for scoring the capability of suspended growth secondary clarifiers are: configuration, surface overflow rate (SOR), depth, return sludge removal mechanism, and return sludge control. The scoring system for these parameters is presented in Table 2-4.

Table 2-4. Parameters for Scoring Capability of Clarifiers in Suspended Growth POTWs

Current Operating Condition	Points
Configuration	
Circular with "donut" or interior launders	10
Circular with weirs on walls	5
Rectangular with 33% covered with launders	5
Rectangular with 20% covered with launders	0
Rectangular with launder at or near end	-10
Surface Overflow Rate, $m^3/m^2/d$ (gpd/sq ft)(1):	
12 (300)	15
20 (550)49 (1,200)	10
27 (650)	5
33 (800)	0
41 (1,000)	-10
49 (1,200)	-15
Depth at Weirs, m (ft):	
4.6 (15)	10
3.7 (12)	4
3.0 (10)	0
2.4 (8)	-5
2.1 (7)	-10
Return Sludge Removal:	
Circular, rapid withdrawal	10
Circular, scraper to hopper	8
Rectangular, cocurrent scraper	2
Rectangular, countercurrent scraper	0
No mechanical removal	-5
Return Activated Sludge Control:	
Actual RAS flow range completely within typical RAS flow range; capability to measure RAS flow	10
Actual RAS flow range completely within typical RAS flow range; no capability to measure RAS flow	7
50% of typical RAS flow range covered by actual RAS flow range; capability to measure RAS flow	5
50% of typical RAS flow range covered by actual RAS flow range; no capability to measure RAS flow	0
Actual RAS flow range completely outside typical RAS flow range	-5

The configuration score is applied to assist in assessing those clarifiers that have diminished capabilities due to poor weir locations or poor surface development with weirs. For example, a clarifier 15-m long and 3-m wide (total surface area of 45 m^2) with a two-sided 1-m wide weir located 1 m from the end is judged to have 9 m^2 of launder coverage [(3 m wide) x (1 m + 1 m + 1 m)], or only 20 percent of the surface area developed. This clarifier's score would be low because of the configuration.

Surface overflow rate is calculated independently of the configuration evaluation and is based on the total clarifier surface area, as follows:

SOR = Wastewater Flow from the Clarifier
÷ Clarifier Surface Area

Typically, the peak month daily average wastewater flow for the most recent 12 months is used to calculate SOR. Peak flow is used to ensure that clarifier is capable of meeting monthly average effluent requirements.

Note: If diurnal flow variations are greater than 2:1 (peak daily flow:daily average flow) the points for SOR must be adjusted to lower values. Conversely, if a clarifier is loaded at a relatively constant rate due to the availability of flow equalization, the points for SOR can be adjusted upward. It must be remembered that the assessment is not a design evaluation but an assessment of whether the clarifier can be made to perform under the desired conditions. In POTWs where special allowance has been made for high infiltration/inflow, such as permitted bypassing above a certain flow, the flow at which secondary treatment is required should be used.

Depth and return sludge removal scores are derived by comparing existing facilities with the conditions shown in Table 2-4. Evaluation of return activated sludge control is based on the ability to control the return flow rate within the typical range for the particular type of activated sludge plant. Typical ranges for return activated sludge pumping rates are presented in Table 2-5.

Table 2-5. Typical Ranges for Return Activated Sludge Pumping Capacities

Process Type	Return Activated Sludge
	% of average daily wastewater flow
Conventional A. S. and Activated Bio-filters (plug flow or complete mix)	25-100
Extended Aeration (including oxidation ditches)	50-100
Contact Stabilization	50-125

c. Sludge Handling Capability

The capability of sludge handling facilities associated with an activated sludge plant is scored by the controllability of the wasting process and the capability of the available sludge treatment and ultimate disposal facilities. Scoring for sludge handling capability is not straightforward because existing facilities cannot be easily assessed due to the variability that exists in design and operational "standards" for unit process capability. To evaluate the sludge handling capability, the evaluator must first calculate expected sludge production based on current loadings to the wastewater treatment processes. The evaluator then assesses the capability of the existing sludge facilities to handle the expected sludge production.

The criteria and point system for evaluating sludge handling capability are presented in Table 2-6. As indicated by the lower points allocated, controllability is much less important than capacity.

Table 2-6. Criteria for Scoring Sludge Handling Capability for Suspended Growth POTWs

Current Operating Condition	Points
Controllability:	
Automated sampling and volume control	5
Metered volume and hand sampling	3
Hand measured volume and hand sampling	2
Sampling or volume measurement by hand not practical	0
Capability:	
150% of calculated sludge production	25
125% of calculated sludge production	20
100% of calculated sludge production	15
75% of calculated sludge production	0
50% of calculated sludge production	-10

Controllability of the wasting process is indicated by the type of waste sludge volume measurement and the type of waste sludge sampling available. The optimum control for an activated sludge wasting system includes automatic volume control and automatic sampling. A positive displacement pump and automatic sampler, both controlled by an accurate and precise clock, is an example of this type of control.

Most small activated sludge plants can manually measure a wasted volume (depth increase in holding tank or digester, or the number of tank trucks filled) and manually sample (from a tap or the open end of the waste sludge line). Most larger plants have flow measuring and totaling devices on waste sludge lines.

Capability of existing sludge handling facilities is evaluated using the following procedures:

- Determine current plant loadings and calculate expected sludge production.
- Establish capability of existing sludge handling unit processes.
- Determine percentage of the expected sludge production each unit process can handle.
- Identify the "weakest link" process as the overall capability of the existing sludge handling facilities and compare to scoring values in Table 2-6.

Expected sludge production is calculated using current BOD_5 loadings (unless believed inaccurate) and typical unit sludge production values for the existing wastewater treatment processes (17). Typical unit sludge production values for various processes are shown in Table 2-7. For example, an oxidation ditch removing about 1,000 kg BOD_5/d would be expected to have an average sludge production of about 650 kg TSS/d (1,000 kg BOD_5/d x 0.65 kg TSS/kg BOD_5 removed).

When plant records include sludge production data, the actual unit sludge production value should be compared to the typical value. If a discrepancy greater than 15 percent exists between these values, further

Table 2-7. **Unit Sludge Production Values for Projecting Sludge Production From Suspended Growth POTWs**

Process Type	kg TSS (sludge)/ kg BOD_5 removed
Activated Sludge w/Primary Clarification	0.7
Activated Sludge w/o Primary Clarification	
Conventional[a]	0.85
Extended Aeration[b]	0.65
Contact Stabilization	1.0

[a] Includes tapered aeration, step feed, plug flow, and complete mix with wastewater detention times < 10 hours.

[b] Includes oxidation ditch.

evaluation is warranted. If actual plant data fall within the 15 percent range, these data can be used for the evaluation of sludge handling capability. A detailed example of calculating expected sludge production and comparing it with plant data is included in Section 2.3.5.

Often plant sludge production data is not reliable and cannot be used to accurately assess sludge handling capability. The most common causes of inaccurate recorded sludge production are:

- Excessive solids loss over the final clarifier weirs
- Inaccurate waste volume measurement
- Insufficient waste sampling and concentration analyses
- Inaccurate determination of BOD_5 removed

Using the unit sludge production values and projected desired BOD_5 removals for the subject plant (desired effluent BOD_5 should meet effluent requirements), the expected mass of sludge produced per day can be calculated. To complete the scoring of sludge handling capability, the expected volume of sludge produced per day must also be calculated. Typical waste sludge concentrations for activated sludge plants are presented in Table 2-8 and can be used to convert the expected mass of sludge produced per day to the expected volume of sludge produced per day.

Variations in sludge production values have been observed throughout the year. Additionally, operation decisions to lower sludge inventories in the plant can place increased requirements on the sludge handling facilities. It is not uncommon for these variations to require 125-150 percent of the long-term average sludge production value (17). For this reason, a factor of 1.25 is applied to the calculated sludge mass and volume values to ensure reliable capability under most operational situations throughout the year.

The capability of each of the components of the sludge handling process are evaluated with respect to its ability to handle the calculated sludge production based on current loadings (the mass and volume values adjusted by the 1.25 factor are used in this evaluation). Using this evaluation approach, sludge handling "bottlenecks" can be identified.

Table 2-8. **Sludge Concentrations for Projecting Sludge Production From Suspended Growth POTWs**

Sludge Type	Waste Concentration
	mg/l
Primary	50,000
Activated	
Return Sludge/Conventional	6,000
Return Sludge/Extended Aeration	7,500
Return Sludge/Contact Stabilization	8,000
Return Sludge/small plant with low SOR[a]	10,000
Separate waste hopper in sec. clarifier	12,000

[a] Returns can often be shut off for short periods to thicken waste sludge in clarifiers with SORs less than 20 $m^3/m^2/d$ (500 gpd/sq ft).

Typical components found in activated sludge facilities are: thickening, digestion, dewatering, hauling, and disposal. Guidelines for the capability evaluation of the components of the existing sludge handling processes are provided in Tables 2-9 and 2-10. The guidelines provided in Table 2-9 are used to compare existing facility capability to calculated sludge production. For example, an exist-ing aerobic digester with a volume of 380 m^3 (100,000 gal) in a plant with a calculated waste sludge volume of 19 m^3/d (5,000 gpd) would have a hydraulic detention time of 20 days. This is 133 percent of the guidelines (15 days) provided for aerobic digesters in Table 2-9. Thus, this compo-nent of the sludge handling process in this particular POTW would have capability for 133 percent of the calculated sludge production. If the aerobic digester proved to have the lowest capability to handle the calculated sludge production of all the components of the sludge handling processes in this POTW, sludge handling capability would score 22 points (interpolated from Table 2-6). The sludge handling capability evaluation is illustrated as part of the CPE example presented in Section 2.3.8.

d. Suspended Growth Major Unit Process Analysis

A worksheet is presented in Appendix L to facilitate the suspended growth major unit process evaluation. Once individual major unit processes are evaluated and given a score, these results should be recorded on a summary sheet, as shown in Table 2-11, and compared with standards for each major unit process and the total plant. This analysis results in the subject POTW being rated a Type 1, 2, or 3 facility, as described in Section 2.2.1.1. The sum of the points scored for aeration basin, secondary clarifier, and sludge handling capability must be 60 or above for the subject POTW to be designated a Type 1 facility.

Furthermore, regardless of total points, the aerator must score at least 13 points, the secondary clarifier at least 25 points, and sludge handling capability at least 10 points for the plant to be considered Type 1.

If the subject POTW meets the criteria for a Type 1 plant, the evaluation has indicated that all major processes have adequate capability for the plant to provide desired performance. If the total is less than 60 points, or if any one major unit process scores less than its minimum, the facilities must be designated as Type 2 or 3.

The minimum criteria for a Type 2 plant are 20 total points and zero for each individual process. If the total is less than 20, or if any major process scores a negative value, the POTW must be considered inadequate and the plant designated as Type 3. Type 3 plants generally require major modifications before they can be expected to meet secondary treatment effluent limits.

Table 2-9. Guidelines for Evaluating Capability of Existing Sludge Handling Processes[a]

Process	Parameters That Can Be Used to Represent 100% of Required Sludge Handling Capability[b]
Gravity Thickeners	
Primary Sludge	125 kg/m^2/d (25 lb/d/sq ft)
Activated Sludge	20 kg/m^2/d (4 lb/d/sq ft)
Primary + Activated	50 kg/m^2/d (10 lb/d/sq ft)
Fixed Film	40 kg/m^2/d (8 lb/d/sq ft)
Primary + Fixed Film	75 kg/m^2/d (15 lb/d/sq ft)
Dissolved Air Flotation	
Activated Sludge	50 kg/m^2/d (10 lb/d/sq ft)
Primary + Activated	100 kg/m^2/d (20 lb/d/sq ft)
Fixed Film	75 kg/m^2/d (15 lb/d/sq ft)
Primary + Fixed Film	125 kg/m^2/d (25 lb/d/sq ft)
Digesters	
Aerobic	15 days' HDT[c]
Anaerobic	
Single Stage	40 days' HDT
Two Stage	30 days' combined HDT
Drying Beds	Worst season turnover time
Mechanical Dewatering	
Single Unit	30 hours of operation/week
Multiple Units	60 hours of operation/week (with one unit out of service)
Liquid Sludge Haul	
Short Haul (<3 km)	6 trips/day maximum
Long Haul (>20 km)	4 trips/day maximum

[a] These guidelines are not developed to meet the proposed new Federal sludge regulations.

[b] Capability of existing unit processes should not be downgraded to these values if good operation and process performance are documented at higher loadings. For example, if records appear accurate and show that all sludge production has been successfully thickened in a gravity activated sludge thickener for the past year at an average loading of 25 kg/m^3/d (5 lb/d/sq ft), the existing thickener should be considered to have 100% of required capability.

[c] HDT = Hydraulic detention time = Volume of digester ÷ Volume of waste sludge calculated to be produced.

Table 2-10. Miscellaneous Unit Values Used in Evaluating Sludge Handling Capability[a]

	Digester HDT[b]	Total Solids Reduction	Output Solids Conc.
	days	%	mg/l
Aerobic Digesters Following	10	10	12,000
Extended Aeration	15	20	15,000
(MCRT >20 d)	20	30	17,000
	>30	35	20,000
Aerobic Digesters Following	10	20	12,000
Conventional A. S.	15	35	15,000
(MCRT <12 d)	>20	40	17,000
Anaerobic Digesters for	20	25	= input
Activated + Primary, and	30	35	= input
Fixed Film + Primary (Supernating Capability Usable)	40	45	= input
WAS Volatile Solids Content			
Conv. (MCRT <12 d)		80%	
Ext. Aer. (MCRT >20 d)		70%	

[a] Values in table are intended for use in allowing an evaluation of sludge handling capability to proceed in the absence of available plant data. Many other variables can affect the values of the parameters shown.

[b] HDT = Hydraulic detention time = Volume of digester ÷ Volume of waste sludge expected to be produced.

A suspended growth POTW that scored the following during the evaluation of major unit processes would meet the criteria for a Type 3 plant:

	Points Scored	Points Required		
		Type 1	Type 2	Type 3
Aeration Basin	14	13-30	0-12	<0
Secondary Clarifier	-8	25-55	0-24	<0
Sludge Handling	10	10-30	0-9	<0
Total	16	60-115	20-59	<20

The point system in Table 2-11 has been developed to aid in assessing the capability of a POTW's major physical facilities. It cannot replace the overall judgment and experience of the evaluator, which should be the deciding factor in determining the capability of facilities to provide improved performance.

2.3.3.2 Fixed Film Major Unit Processes

Fixed film facilities covered in this manual include those trickling filter plants using rock or plastic media plus those using the RBC or activated bio-filter (ABF) variations of the basic process. The unit process in fixed film wastewater treatment plants that most significantly affects capacity and performance is the "aerator" portion of the plant (i.e., the amount and type of trickling filter media, RBC media, etc.) Other significant unit processes are the secondary clarifier and sludge handling capability.

Table 2-11. Suspended Growth Major Unit Process Capability Evaluation

	Points Scored	Points Required*		
		Type 1	Type 2	Type 3
Aeration Basin	____	13-30	0-12	<0
Secondary Clarifier	____	25-55	0-24	<0
Sludge Handling	____	10-30	0-9	<0
Total	____	60-115	20-59	<20

* Each unit process as well as the overall points must fall in the designated range for the plant to achieve the Type 1 or 2 rating.

Table 2-12. Parameters for Scoring Aerator Capability for Trickling Filter POTWs

	Points	
Current Operating Condition	Freezing Temp.[b]	Covered Filter or Nonfreezing Temp.
BOD_5 Loading, kg $BOD_5/m^3/d$ (lb/d/1,000 cu ft):[a]		
0.16 (10)	20	20
0.32 (20)	15	20
0.48 (30)	0	10
0.80 (50)	-10	-5
1.12 (70)	-20	-10
Recirculation, ratio to raw flow:		
2:1	3	
1:1	2	
None	0	
Anaerobic Sidestreams:[c]		
Not returned to plant	0	
Returned to wastewater stream ahead of the TF:		
Returned to flow equalization tank or prior to primary	-6	
clarifier	-10	
Returned directly ahead of TF		

[a] Based on primary effluent and common rock media having a specific surface area of about 43 m^2/m^3 (13 sq ft/cu ft).

[b] Temperatures below freezing for more than one month.

[c] Supernatant from anaerobic digesters or filtrate/concentrate from the dewatering processes following anaerobic digesters.

a. Aerator

Trickling Filters

An approach to develop "equivalency" is used to allow a comparable evaluation of the potential performance capability of trickling filters of varying media types. It is not intented that this equivalency approach be used as a basis of design. The unit surface area for common rock media is typically 43 m^2/m^3 (13 sq ft/cu ft) (3). This information can be used to convert data from trickling filters with artificial media to roughly equivalent volumes of common rock media. For example, 1,000 m^3 (3,500 cu ft) of a plastic media with a specific surface area of 89 m^2/m^3 (27 sq ft/cu ft) is roughly equivalent to [(89/43) x (1,000 m^3)] or 2,070 m^3 (7,300 cu ft) of common rock media. Unit surface area information for various media types is generally available in manufacturers' literature.

Using the equivalency calculation, BOD_5 loadings can be calculated for all types of media. Loadings for trickling filters are typically expressed as mass of BOD_5 per volume of media. The volumetric loading can be calculated using the equivalency calculation presented above. Results can be compared with criteria in Table 2-12 to compute a "score" for the trickling filter.

The capability of a trickling filter can be significantly decreased if plugging occurs. Ponding on the filter is a common indicator of plugging and can be due to overgrowth of microorganism mass, disintegration of the media, or underdrain blockage or damage. The evaluator should inspect the filter in several places (removing media where possible) to ensure that ponding underneath the upper layer of rocks is not occurring.

RBCs

Parameters for scoring RBCs are presented in Table 2-13 (18). The key parameters to be evaluated are: BOD_5 loading on the first stage and on the entire system; number of stages provided; and whether or not sidestreams from anaerobic sludge treatment are received. BOD_5 loading used for evaluating RBCs is soluble BOD_5 ($SBOD_5$) per unit of media. If data are not available, $SBOD_5$ is estimated for typical domestic wastewater as 0.4 of the primary effluent total BOD_5 ($TBOD_5$). If significant industrial contributions are present in the system, $SBOD_5$ should be determined by testing.

Surface area data for RBCs are generally available in manufacturers' literature or in plant O&M manuals. If these sources are unavailable or do not contain the needed information, the manufacturer's representative or the manufacturer should be contacted to obtain the data.

First-stage media loading is calculated by dividing the mass of $SBOD_5$ going to the first stage by the total surface area of only the first-stage media. System media loading is calculated by dividing the total $SBOD_5$ load to the RBCs by the total surface area of all RBC media. In most cases, the mass of $SBOD_5$ will be the same for these calculations. They should only be different in plants where some of the $SBOD_5$ load is bypassed around the first stage.

ABFs

Parameters for evaluating ABF aerators are presented in Table 2-14 (19). The key parameters are: biocell BOD_5 loading and aeration basin detention time. A criterion of lesser importance is recirculation directly around the biocell.

Table 2-13. Parameters for Scoring Aerator Capability for RBC POTWs[a] (7)

Current Operating Condition	Points
First-Stage Loading, g $SBOD_5/m^2/d$ (lb/d/1,000 sq ft):	
12 (2.5)	10
20 (4.0)	0
29 (6.0)	-6
System Loading g $SBOD_5/m^2/d$ (lb/d/1,000 sq ft):	
2.9 (0.6)	10
4.9 (1.0)	0
7.3 (1.5)	-6
Number of Stages:	
4	10
3	7
2	4
Anaerobic Sidestreams:	
Not returned to plant	0
Returned to wastewater stream ahead of RBC	
Returned to flow equalization tank or prior to primary clarifier	-6
Returned directly ahead of RBC	-10

[a] Includes mechanical and air drive RBCs.

[b] Supernatant from anaerobic digesters or filtrate/concentrate from the dewatering processes following anaerobic digesters.

Table 2-14. Parameters for Scoring Aerator Capability for ABF POTWs (19)

Current Operating Condition	Points
Biocell BOD_5 Loading, kg $BOD_5/m^3/d$ (lb/d/1,000 cu ft):	
1.6 (100)	15
2.4 (150)	10
2.8 (175)	5
3.2 (200)	0
4.0 (250)	-5
4.8 (300)	-10
Aeration Basin Detention Time, hours:	
4	20
3	15
2	12
1	5
0.75	0
0.5	-10
Oxygen Availability in Aeration Basin, kg O_2/kg BOD_5 to Biocell:	
1.0	10
0.75	7
0.5	3
0.4	0
0.3	-15
Recirculation - Directly Around Biocell, ratio to raw flow:	
1:1	3
None	0

BOD_5 loadings on the biocell are calculated in a manner similar to trickling filter loadings: primary effluent BOD_5 mass is divided by the volume of the biocell media. Aeration basin detention time is calculated in a manner similar to activated sludge aeration basin hydraulic detention time: the aeration basin liquid volume is divided by the average daily wastewater flow. Sludge recirculation is not included in this calculation. Typically, peak month daily average flow for the most recent 12 months is used to ensure that adequate detention time exists to meet the monthly average effluent requirements.

Oxygen availability in the aeration basin of an ABF plant is calculated by dividing mass of oxygen transfer capacity by the total mass of BOD_5 applied to the biocell. This is done because the removal attributed to the biocell versus that occurring in the aeration basin is not easily distinguished. Most ABF plants provide for recirculation directly around the biocell. Recirculation is calculated as a ratio to raw flow (typically, the peak month daily average flow).

b. Secondary Clarifier

Criteria for scoring the capability of secondary clarifiers in trickling filter and RBC plants are presented in Table 2-15. The calculations require that wastewater flow rate and the clarifier configuration, surface area, and depth be known (see Section 2.3.3.1). For ABF plants, the criteria for suspended growth secondary clarifiers presented in Tables 2-4 and 2-5 are more appropriate and should be used.

Table 2-15. Parameters for Scoring Capability of Clarifiers in Trickling Filters and RBCs*

Current Operating Condition	Points
Configuration:	
Circular with "donut" or interior launders	10
Circular with weirs on walls	5
Rectangular with 33% covered with launders	5
Rectangular with 20% covered with launders	0
Rectangular with launder at or near end	-10
Surface Overflow Rate, $m^3/m^2/d$ (gpd/sq ft):	
12 (300)	15
20 (500)	10
27 (650)	5
33 (800)	0
41 (1,000)	-10
49 (1,200)	-15
Depth at Weirs:	
3.7 (12)	5
3.0 (10)	3
2.1 (7)	0

* For ABF plants, criteria for suspended growth clarifiers (Table 2-4) should be used.

c. Sludge Handling Capability

Criteria for scoring sludge handling capability associated with fixed film plants are presented in Table 2-16. The criteria for controllability in Table 2-16 are self-explanatory. The capability of sludge handling associated with fixed film facilities is evaluated using the same approach presented in Section 2.3.3.1 for suspended growth POTWs.

Different unit sludge production values are used in calculating expected sludge production from fixed film facilities. Typical unit sludge production values for the various types of fixed film plants are summarized in

Table 2-16. Criteria for Scoring Sludge Handling Capability for Fixed Film POTWs

Current Operating Condition	Points
Controllability:	
Automated sampling and volume control	5
Metered volume and hand sampling	3
Hand measured volume and hand sampling	2
Sampling or volume measurement by hand not practical	0
Capability:	
125% of calculated sludge production	25
100% of calculated sludge production	15
75% of calculated sludge production	5
50% of calculated sludge production	-10

Table 2-17. Unit Sludge Production and Sludge Concentration Values for Projecting Sludge Production From Fixed Film POTWs (1,21,26)

Process Type	kg TSS (sludge)/ kg BOD_5 removed
Trickling Filter	0.9
RBC	1.0
ABF	1.0
Sludge Type:	Waste Conc., mg/l
Primary	50,000
Primary + Trickling Filter	35,000
Primary + RBC	35,000
Primary + ABF	30,000
Trickling Filter	20,000
RBC	20,000
ABF	10,000

Table 2-18. Trickling Filter Major Unit Process Capability Evaluation

	Points Scored	Points Required* Type 1	Type 2	Type 3
"Aerator"	____	17-23	0-11	<0
Secondary Clarifier	____	17-30	0-16	<0
Sludge Handling	____	10-30	0-9	<0
Total	____	45-83	15-44	<15

* Each unit process as well as the overall points must fall in the designated range for the plant to achieve the Type 1 or 2 rating.

Table 2-17. A detailed example of calculating expected sludge production and comparing it with data is included in Section 2.3.5.

Frequently, secondary sludge from fixed film facilities is returned to the primary clarifiers. Typical underflow concentrations of the combined sludge from the primary clarifier are shown in Table 2-17 as well as sludge concentrations from the individual fixed film processes.

The guidelines presented in Tables 2-9 and 2-10 can be used to help an evaluator assess the performance potential of existing sludge treatment and disposal facilities.

d. Fixed Film Major Unit Process Analysis

Worksheets are presented in Appendices M, N, and O to facilitate the fixed film major unit process evaluation. Once major fixed film unit processes are evaluated, they should be summarized and compared to standards for each type of fixed film facility. Tables 2-18, 2-19 and 2-20 can be used for this purpose.

This analysis results in the subject POTW being rated Type 1, 2, or 3, as described in Section 2.3.3.1. Using these tables, the subject plant must score the minimum number of points listed for each individual process and the minimum number total points for all processes for the plant to qualify for a specific plant type. For example, a trickling filter plant scoring the following would meet the criteria for a Type 1 facility for overall points, aerator, and secondary clarifier, but would be classified Type 2 because of its score for sludge handling capability:

	Points Scored	Points Required Type 1	Type 2	Type 3
"Aerator"	21	17-23	0-11	<0
Secondary Clarifier	27	17-30	0-16	<0
Sludge Handling	6	10-30	0-9	<0
Total	54	45-83	15-44	<15

Table 2-19. RBC Major Unit Process Capability Evaluation

	Points Scored	Points Required* Type 1	Type 2	Type 3
"Aerator"	____	14-30	0-13	<0
Secondary Clarifier	____	17-30	0-16	<0
Sludge Handling	____	10-30	0-9	<0
Total	____	48-90	15-47	<15

* Each unit process as well as the overall points must fall in the designated range for the plant to achieve the Type 1 or 2 rating.

Table 2-20. ABF Major Unit Process Capability Evaluation

	Points Scored	Points Required* Type 1	Type 2	Type 3
"Aerator"	____	15-48	0-14	<0
Secondary Clarifier	____	20-55	0-19	<0
Sludge Handling	____	10-30	0-9	<0
Total	____	50-133	15-49	<15

* Each unit process as well as the overall points must fall in the designated range for the plant to achieve the Type 1 or 2 rating.

2.3.3.3 Stabilization Pond Processes

Stabilization pond treatment systems combine the "aerator" function, secondary clarification, and sludge handling into one unit process. Typical pond facilities include facultative and aerobic systems. Process evaluation is based on the relaxed effluent limitation for total suspended solids available for pond systems (e.g., 75 mg/L effluent TSS for facilities less than 2 mgd capacity).

a. Facultative Pond Facilities

The parameters that are used for scoring the capability of facultative stabilization pond facilities and the point system for scoring these parameters is presented in Table 2-21. To obtain the necessary parameters, the evaluator must collect information on wastewater flow, BOD$_5$ strength, the minimum average winter air temperature, pond dimensions, and the type of flexibility provided with the facility.

Once data are available on these parameters, the following calculations should be completed by the evaluator:

BOD$_5$ Loading = Influent BOD$_5$ ÷ Surface Area of All Ponds

(Influent BOD$_5$ mass is typically the daily average value for the most recent 12 months)

Detention Time = Total Pond Volume ÷ Average Daily Flow

(Flow is typically the daily average value for the most recent 12 months)

To evaluate the possibility of short-circuiting, the following ratios should be calculated:

Short-Circuiting Ratio = Distance From Inlet To Outlet ÷ Maximum Pond Dimension

Length-to-width Ratio = Maximum Pond Dimension ÷ Minimum Pond Dimension

(The ratios for each pond should be calculated, then these values should be averaged)

When the above calculations have been completed for the subject POTW, the results are compared to the values given in Table 2-21 and appropriate points are assigned each parameter. If the parameters for the subject POTW fall between the values listed, interpolation is used to assign appropriate points.

Table 2-21. Parameters for Scoring Capability of Facultative Stabilization Pond Systems* (24,25)

Current Operating Condition	Points
Average Winter Air Temperature >15°C	
BOD$_5$ Loading, kg BOD$_5$/ha/d (lb/ac/d):	
45 (40)	10
67 (60)	5
90 (80)	0
112 (100)	-5
134 (120)	-10
1st Pond Loading >101 kg BOD$_5$/ha/d (>90 lb/ac/d)	-3
Detention Time, days	
30	5
20	0
15	-5
Average Winter Air Temperature 0-15°C	
BOD$_5$ Loading, kg BOD$_5$/ha/d (lb/ac/d):	
11 (10)	10
22 (20)	5
45 (40)	0
67 (60)	-5
90 (80)	-10
1st Pond Loading >73 kg BOD$_5$/ha/d (>65 lb/ac/d)	-3
Detention Time, days	
80	5
30	0
20	-5
Average Winter Air Temperature <0°C	
BOD$_5$ Loading, kg BOD$_5$/ha/d (lb/ac/d):	
11 (10)	10
17 (15)	5
22 (20)	0
34 (30)	-5
45 (40)	-5
1st Pond Loading >39 kg BOD$_5$/ha/d (>35 lb/ac/d)	-3
Detention Time, days	
100	5
50	0
40	-5
Number of Ponds in Series:	
3	5
2 Applies to # ponds in series	0
1	-5
Length to Width Ratio:	
>2	2
1.5-2 Applies to length-to-width	0
<1.5	-2
Ratio of Inlet-Outlet Distance to Max. Pond Dimension (Short Circuiting Ratio):	
>0.75	2
0.5-0.75	0
<0.5	-2
Flexibility to Operate in Series and Parallel:	
Available	3
Not Available	0
Variable Level Draw-Off:	
Available	3
Not Available	-3

* Interpolate to nearest whole number between loadings listed..

b. Aerated Pond Facilities

The parameters used for scoring the capability of aerobic stabilization pond facilities and the point system for scoring these parameters are presented in Table 2-22. They are similar to parameters used to evaluate facultative facilities with the exception of the oxygen availability and mixing parameters. To obtain the necessary parameters, the evaluator must collect information on wastewater flow, BOD_5 strength, oxygen transfer capacity, mixing energy, pond dimensions, and the type of flexibility provided with the facility. With the exception of oxygen availability and mixing energy, the calculations for these parameters are discussed in Section 2.3.3.3a. For information on evaluating oxygen availability, refer to Section 2.3.3.1.

Table 2-22. Parameters for Scoring Capability of Aerated Stabilization Pond Systems* (24, 25)

Current Operating Condition	Points
BOD_5 Loading, kg BOD_5/ha/d (lb/ac/d): [based on aerated ponds only]	
56 (50)	16
112 (100)	8
168 (150)	0
224 (200)	-5
280 (250)	-10
Detention Time, days	
40	5
15	0
10	-5
Number of Ponds in Series:	
3	10
2	0
1	-10
Length to Width Ratio:	
>2	2
1.5-2	0
<1.5	-2
Ratio of Inlet-Outlet Distance to Max. Pond Dimension (Short Circuiting Ratio):	
>0.75	2
0.5-0.75	0
<0.5	-2
Oxygen Availability, kg O_2/kg BOD_5 load:	
2.0	10
1.5	5
1.2	0
1.0	-5
0.8	-10
Mixing Energy (aerated ponds only), kW/1,000 m^3 (hp/10^6 gal):	
3 (15)	5
2 (10)	3
1 (5)	0
Flexibility to Operate in Series and Parallel:	
Available	3
Not Available	0
Variable Level Draw-Off Discharge:	
Available	3
Not Available	-3

* Interpolate to nearest whole number between loadings listed..

The mixing energy parameter is calculated as follows:

Mixing Energy = Total Energy in Primary Pond
÷ Primary Pond Volume

(Total energy includes energy used for aeration and mixing)

When the above calculations have been completed for the subject POTW, the results are compared to the values given in Table 2-22 and appropriate points are assigned each parameter. If the parameters for the subject POTW fall between the values listed, interpolation is used to assign appropriate points.

c. Stabilization Pond Process Analysis

A worksheet is presented in Appendix P to facilitate the stabilization pond process evaluation. Once the stabilization pond process has been evaluated and given a score, results should be compared with the categories shown in Table 2-23. This analysis results in the subject POTW being rated a Type 1, 2, or 3 facility, as described in Section 2.2.1.1. The sum of the points scored for a facultative pond system must be 16 or above for the subject POTW to be designated a Type 1 facility. For an aerobic pond system the total points scored must be 21 or above for this same ranking. If the subject POTW meets the criteria for a Type 1 plant, the evaluation has projected that the facility has adequate capability within the physical facilities to achieve compliance with the related definition of secondary treatment for pond systems. If the total points for the facility are less than 16 for a facultative pond system or 21 for an aerobic pond system, the facility must be designated as Type 2 or 3.

Table 2-23. Stabilization Pond Process Capacity Evaluation

	Points Scored	Points Required		
		Type 1	Type 2	Type 3
Facultative Facilities	____	>15	0-15	<0
Aerobic Facilities	____	>20	5-20	<5

2.3.4 Evaluation of Performance-Limiting Factors

Identification of performance-limiting factors should be completed at a location that allows all potential factors to be discussed openly and objectively (e.g., away from the plant staff). The checklist of performance-limiting factors presented in Appendix A, as well as the guidelines for interpreting these factors, provide the structure for an organized review of problems in the subject POTW. The intent is to identify as clearly as possible the factors that most accurately describe the causes of limited performance. For example, poor activated sludge operation may be causing poor plant performance because the operator is improperly applying activated sludge concepts. If the operator is solely responsible for process control decisions as well as for testing for these decisions, the factor of improper application of concepts should be identified.

Often, operator inability can be traced to another source, such as an O&M manual containing inaccurate information or a technical consultant who provides routine assistance to the operator. In this case, improper application of concepts plus the source of the problem (O&M manual or inappropriate technical guidance) should be identified as performance-limiting factors, since both must be corrected to achieve desired plant performance.

Whereas the checklist and guidelines in Appendix A provide the structure for the identification of performance-limiting factors, notes taken during the plant tour and detailed data-gathering activities (including the completed forms from Appendix D) provide the resources for identifying these factors.

Each factor identified as limiting performance should be assigned an "A," "B," or "C" rating as discussed in Section 2.2.1.3. Further prioritization is accomplished by completing the summary sheet presented in Appendix B. Only those factors receiving either an "A" or "B" rating are prioritized on this sheet. Additional guidance for identifying and prioritizing performance-limiting factors is provided in the following sections for the general areas of administration, design, operation, and maintenance.

2.3.4.1 Administration Factors

Budgeting and financial planning are the mechanisms whereby POTW owners/administrators generally implement their objectives. Therefore, evaluation and discussion of these aspects is an integral part of efforts to identify the presence of administrative performance-limiting factors. For this reason, early during the on-site fieldwork, the evaluator should schedule a meeting with the key POTW decision-maker and the "budget person." This meeting should be scheduled after the evaluator is familiar with the plant.

Nearly every POTW's financial information is set up differently so it helps to review the information with the assistance of plant personnel to realistically rearrange the line items into categories understood by the evaluator. Forms for collecting financial data are presented in Appendix D. Analysis of these data can be supported by comparison with typical values for wastewater treatment plants (16,20,21). POTWs with flows greater than 88 L/s (2 mgd) usually have separate financial information for the wastewater treatment facilities. Smaller POTWs often have financial information combined with other utilities, such as wastewater collection, water treatment and distribution, or even street repairs and maintenance. For this reason, it is often more difficult and time consuming to assess the financial status for small POTWs.

Key POTW administrators should be identified and individual interviews scheduled with them as described in Section 2.3.3.1. As a general rule, the individual interviews should be held in an environment that allows for open discussion.

The evaluation of administrative performance-limiting factors is by nature subjective. Typically, all administrators verbally support goals of low costs, safe working conditions, good treatment performance, high employee morale, etc. An important question that the evaluator must ask is, "Where does good treatment fit in?" Often this question can be answered by observing the priority of items implemented or supported by administrators. The ideal situation is one in which the administrators function with full awareness that they want to achieve desired performance as an end product of their wastewater treatment efforts. Improving working conditions, lowering costs, and other similar goals would be pursued within the realm of first achieving adequate performance.

At the other end of the spectrum is an administrative attitude that "we just raised the monthly rates 100 percent last year; we can't afford to spend another dime on that plant." POTW administration can be judged by the following criteria:

Excellent: Reliably provides adequate wastewater treatment at lowest reasonable cost.

Normal: Provides best possible treatment with the money available.

Poor: Spends as little as possible with no correlation made to achieving adequate plant performance.

Administrators who fall into the "poor" category typically are identified as contributing to inadequate performance during the factor identification activities.

Technical problems identified by the plant staff or the CPE evaluator, and the potential costs associated with correcting these problems, often serve as the basis for assessing administrative factors limiting plant performance. For example, the plant staff may have correctly identified needed minor modifications for the facility and presented those needs to the POTW administrators, but had their request turned down. The evaluator should solicit the other side of the story from the administrators to see if the administrative policy is indeed non-supportive in correcting the problem. There have been many instances in which operators or plant superintendents have convinced administrators to spend money to "correct" problems that resulted in no improvement in plant performance.

Another area in which administrators can significantly, though indirectly, affect plant performance is through personnel motivation. A positive influence exists if administrators encourage professional growth through support of training, tangible awards for initial or upgrading certification, etc. If, however, administrators eliminate or skimp on essential operator training, downgrade operator positions through substandard salaries, or otherwise provide a negative influence on operator morale, administrators can have a significant detrimental effect on plant performance.

2.3.4.2 Design Factors

Data gathered during the plant tour, completion of forms in Appendix D, and the completed evaluation of major unit process capabilities provide the basic information needed to complete the identification and prioritization of design-related performance-limiting factors. Often, to complete the evaluation of design factors, the evaluator must make field investigation of the operational flexibility of the various unit processes.

Field investigations should be completed in cooperation with the POTW operator. The evaluator must not make any changes unilaterally. Any field testing desired should be discussed with the operator, whose cooperation should be obtained in making any needed changes. This approach is essential since the evaluator may wish to implement changes that, while improving plant performance, could be detrimental to specific equipment at the plant. The operator has worked with the equipment, repaired past failures, and read the manufacturers' literature, and is in the best position to ascertain any adverse impact of proposed changes.

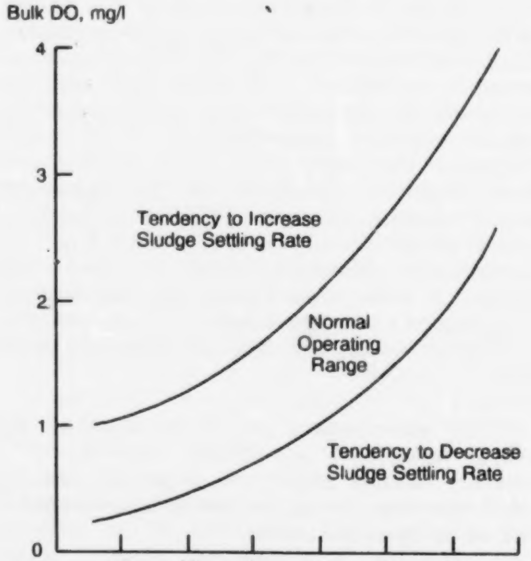
Field investigation of process flexibility defines the limitations of the equipment and processes and also promotes a better understanding of the time and difficulty required to implement better process control. This is illustrated by the following discussion:

> A 4.4-L/s (0.1-mgd) extended aeration facility has airlift sludge return pumps that have been operated to provide return rates of 200-300 percent of influent flow rates. The evaluator desired to know if returns could be held under 100 percent since this would substantially reduce solids loading on the final clarifier and potentially improve clarifier performance.
>
> Discussions with the plant operator revealed that he had previously tried to reduce the return rate by reducing the air to the airlift return pumps. The operator abandoned the idea because the airlifts repeatedly plugged overnight when left at the lower rates. The evaluator convinced the operator to again try reducing the return rate so that the limits of return sludge flow control available could be defined.
>
> Air flow rate was initially reduced to produce a return flow rate of 100 percent of incoming wastewater flow as measured by a bucket and stopwatch. The airlift return pumps plugged completely in less than 2 hours. The return flow rate was reset to 100 percent by increasing the airflow substantially above the previous setting. An hour later the return flow rate was measured as 220 percent. These results supported the operator's contention that return flow rates could not be controlled at reasonable levels.
>
> The air supply was again adjusted to provide a flow rate halfway between the current and the desired rate. This setting allowed better control to be exercised, but plugging still occurred with existing sludge characteristics at return sludge flows of less than about 125 percent. It was concluded that this was the practical lower limit for return sludge flow rate control with the existing facilities and sludge character. To maintain a return sludge in the range of 125-150 percent required frequent checking, including an evening check not before asked of the operator. In this manner, part - but not all - of the design limitation could be overcome with increased operator attention.

The areas in a POTW that frequently require field investigations to determine process flexibility are:

1. *Suspended Growth Systems*
   - Control of return sludge flow rate within the ranges presented in Table 2-5
   - Control of aeration basin DO within the ranges presented in Figure 2-2
   - Sludge mass control by wasting expected sludge production (mass and volume) presented in Tables 2-7 and 2-8
   - Flow splitting to prevent unnecessary overloading of individual process units

Figure 2-2. Effect of aeration basin DO concentrations on sludge settling characteristics.



- Available mode changes to provide maximum use of existing facilities:
  - Step feed or contact stabilization when the final clarifier appears to be a limiting unit process
  - Step feed when oxygen transfer is marginal

2. *Trickling Filters*
   - Alternate disposal methods for anaerobic digester supernatant
   - Ability to control sludge levels in clarifiers without adversely impacting sludge handling facilities
   - Recirculation to the filter without excess hydraulic loads on the primary or secondary clarifiers

3. *RBCs*
   - Alternate disposal methods for anaerobic digester supernatant
   - Ability to control sludge levels in clarifiers without adversely impacting sludge handling facilities
   - Ability to redistribute individual stage loadings to provide unit loadings within the ranges shown in Table 2-13

4. *ABFs*
   - Control of return sludge flow rates within 50-100 percent of influent flow
   - Ability to waste a desired mass of sludge on a daily basis
   - Ability to spread a day's sludge wasting over a 24-hour period, or at least an extended period of time
   - Ability to provide recirculation directly around the biocell
   - Ability to maintain aeration basin DO at 2-3 mg/L

2.3.4.3 Operational Factors

Operational factors are those factors that relate to the unit process control functions implemented at a POTW. Significant performance-limiting factors often exist in these areas (16). The approach and methods used in maintaining process control can significantly affect the performance of plants that have adequate physical facilities. This section provides guidance to evaluators for identification and prioritization of operational factors that limit plant performance.

The evaluator starts collecting data for the process control evaluation by identifying the key POTW person for process control strategies implemented at the plant. The plant tour and data-gathering phases also provide opportunity to assess the process control applied. In addition, the process control capability of an operator can be subjectively assessed during the major unit process evaluation. If an operator recognizes the unit process functions and their relative influences on plant performance, a good grasp of process control is indicated. An approach to evaluating process control is discussed in the following sections.

a. Suspended Growth Facility Process Control

The process controls that should be available to an operator of an activated sludge facility are control of: sludge mass, aeration basin DO, and return sludge rate. Techniques and approaches to improving these controls are presented in Chapter 3.

Sludge Mass Control

The activated sludge process removes colloidal and dissolved organic matter from wastewater resulting in a net increase in the sludge solids in the system. Control of the amount of sludge maintained in the system by wasting (removing) excess sludge is a key element in controlling plant performance. All variations of the activated sludge process require sludge mass control and periodic wasting. In line with this requirement, an operator who properly understands activated sludge mass control should be able to show the evaluator a recorded history of a controlled sludge mass (e.g., records of mean cell residence time [MCRT], mixed liquor volatile suspended solids [MLVSS], plots of MLSS/MLVSS concentrations in the aeration basin, total mass of sludge in the plant, etc.).

The following are common indicators that sludge mass control is not adequately practiced at an activated sludge plant:

- A sludge mass indicator parameter or calculation (MLVSS, MCRT, total sludge units) is not obtained on a routine basis (22). "Routine" would be at least daily for an 88-L/s (2-mgd) or larger plant and 2-3 times a week for a 4.4-L/s (0.1-mgd) plant.
- Only a settled sludge test is used to determine wasting requirements (e.g., waste if the 30-minute settled sludge volume in a graduated cylinder is greater than 600 ml/L).
- The operator does not relate mass control to control of sludge settling characteristics and sludge removal performance (i.e., sludge character).
- Significantly less mass is wasted than calculations indicate should be produced (i.e., the clarifiers lose solids over the weirs routinely).
- Poor performance persists and the mass of sludge maintained provides an MCRT significantly out of the ranges in Table 2-24.

Table 2-24. Typical Mean Cell Residence Times for Suspended Growth POTWs

Process Type	Typical MCRT days
Conventional Aeration	4-12
Extended Aeration	20-40
Contact Stabilization	10-30

Aeration Basin DO Control

The aeration basin DO level is a significant factor in promoting the growth of either filamentous or zoogleal-type sludge organisms (23). Higher DO tends to speed up or slow down the relative populations of these major organism types toward primarily zoogleal. Conversely, lower DO encourages the growth of filamentous organisms and a bulky, slow settling sludge. A general guideline for relating sludge characteristics to DO concentration in an aeration basin is presented in Figure 2-2. This information can be used to evaluate the DO control approach at the POTW under study.

The following are common indicators that aeration basin DO control is not properly practiced at an activated sludge plant:

- DO testing is not run routinely on the aeration basin. "Routine" ranges from daily for an 88-L/s (2-mgd) or large plant to weekly for a 4.4-L/s (0.1-mgd) plant.
- The operator does not understand or use the relationship between DO and sludge character (e.g., sludge settling is very slow and DO is very low, or sludge settling is very fast, effluent is turbid, and DO is very high).

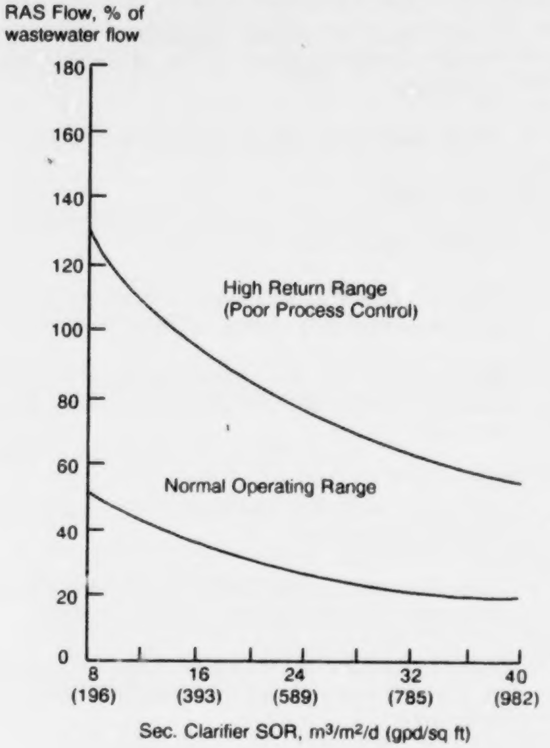
Return Sludge Control

The objective of return sludge flow control is to optimize sludge distribution between the aerator and secondary clarifier to achieve and maintain good sludge characteristics. Thus, return sludge flow rate control should be used to maximize the sludge mass and sludge detention time in the aeration basins and minimize the sludge mass and sludge detention time in the clarifiers.

The following are common indicators that return sludge flow rate control is not properly practiced at an activated sludge plant:

- Returns are operated outside the ranges (especially higher) indicated in Table 2-5 and Figure 2-3.
- The operator believes that a high sludge blanket condition in a final clarifier can be categorically lowered by increasing the sludge return rate. (E.g., the operator does not realize that increasing the return sludge flow rate increases the solids loading to the final clarifier and decreases the settling time in the final clarifier.)

Figure 2-3. Typical return sludge flow rates with various clarifier surface overflow rates.



- MLSS concentrations fluctuate widely on a diurnal basis, but return rates are not adjusted throughout the day to account for diurnal flow variations.
- The operator has not devised a method to estimate or measure the return sludge flow rate if measurement was not provided for in the original design.

b. Fixed Film Facility Process Control

There is a lesser amount of process control that can be applied to fixed film facilities than to suspended growth facilities. However, because fixed film facility performance is so dependent on media loading, process control, which may at first seem unimportant, can make a significant difference in plant performance. The following are common indicators that process control at a fixed film facility is not optimum (1):

- Sludge blankets in either the primary or secondary clarifiers are maintained at a high level [i.e., >0.3 m (1 ft)].
- Organic loads from return process streams are not minimized.

- Lack of good maintenance, indicated by:
  - Distributors on trickling filters are plugged, or leaky distributor seals are not fixed.
  - Filter media is partially plugged and measures such as chlorination, flooding, and recirculation are not used to address the problem.
  - Trickling filter underdrain collector outlets are submerged or air vents are plugged.
- High recirculation, which increases primary or secondary clarifier overflow rates, is provided without regard to clarifier overloading. Some trickling filter plants provide recirculation that is directed to the influent wastewater wet-well and must pass through the primary clarifier a second time. Likewise, some trickling filters provide recirculation through the secondary clarifier sludge return to the head of the plant. Recirculation provided by these methods should not be practiced.

2.3.4.4 Maintenance Factors

General information on POTW maintenance is gathered during the detailed data collection phase and is recorded on Form D-5. However, the evaluation of maintenance performance-limiting factors is done throughout the CPE by observation and questions concerning the reliability and service requirements of pieces of equipment critical to process control and thus performance. If units are out of service routinely or for extended periods of time, maintenance practices may be a significant contributing cause to a performance problem. An adequate spare parts inventory is essential to a good maintenance program. Equipment breakdowns are often used as excuses for process control problems. For example, one operator of an activated sludge plant blamed the repeated loss of sludge over the final clarifier weirs on the periodic breakdown of one sludge return pump. Even with one pump out of service, the return sludge capacity was over 200 percent of influent flow. The real cause of the sludge loss was improper process control, including inadequate sludge mass control and excessively high return sludge flow rates.

Observation and documentation are necessary portions of the approach utilized to evaluate emergency and preventive maintenance practices. Important aspects are examination and verification of spare parts inventories and recordkeeping systems. An example approach to a preventive maintenance scheduling system that has been applied successfully at several plants is presented in Appendix G. A good preventive maintenance program includes a schedule to distribute the workload evenly. Evaluation of these items provides a basis from which the specific results of maintenance, or lack thereof, can be assessed. This approach is illustrated by the following:

> A poorly performing trickling filter plant was assessed to have acceptable BOD_5 loadings to the filter, capable secondary clarifiers, and adequate sludge handling facilities. However, a large buildup of sludge was maintained in both the primary and secondary clarifiers. Questioning of the operator revealed that sludge was not removed adequately because the heated anaerobic digesters were upset if too much sludge is added. Further investigation indicated that adequate temperature control of the digester contents was not being achieved. The operator pointed out that the boiler for the heat exchanger was operated manually and just during the day because he had tried unsuccessfully to fix the automatic controls. Ultimately, inadequate maintenance was identified as a cause of poor plant performance.

The above discussion illustrates how a detailed evaluation of process control activities was necessary to properly identify a maintenance-related factor as a cause of poor plant performance. The evaluator must evaluate maintenance during all phases of the CPE and should not expect to identify these factors solely in a formal evaluation of maintenance procedures.

2.3.5 Performance Evaluation

The plant performance evaluation is directed toward two goals: 1) establishing, or verifying, the magnitude of a POTW's performance problem; and 2) projecting the level of improved treatment that can be expected.

2.3.5.1 Magnitude of the Performance Problem

During the CPE, the evaluator should develop a clear understanding of the performance problem associated with the subject POTW. As a first step of this assessment, recorded historical performance data can be used. These data are available from copies of NPDES permit reports in small POTWs and from monthly monitoring summary sheets in larger POTWs.

Once historical data are reviewed, the evaluator should attempt to verify the accuracy of the reported plant performance. It should be stressed that the purpose is not to blame the plant staff, but rather to assist in identifying and substantiating the true cause(s) of poor plant performance.

The evaluator can indirectly collect data to establish authenticity of the monitoring results throughout the CPE. For example, major unit processes are assessed for their capability to achieve desired performance. If a POTW is rated a Type 3 plant (inadequate major process capability), reported excellent effluent quality should be suspect. If reported performance is consistent with the results of the overall evaluation, the validity and accuracy of the data are reinforced.

Limitations of these comparisons are their subjective nature.

Major test parameters critical for completion of the CPE are influent BOD_5 and flow. The evaluator can roughly check both BOD_5 and flow data by calculating a per capita BOD_5 contribution. Per capita BOD_5 contributions are usually 0.07-0.09 kg (0.15-0.20 lb)/d for typical domestic wastewater. When estimating BOD_5 loads to a plant without actual data, or checking reasonableness of existing plant data, loads from significant industrial contributors must be added to the calculated per capita loads.

Small activated sludge plants have been shown to have the most variance between historical records and actual performance. In small activated sludge plants - such as package extended aeration plants, contact stabilization plants, and oxidation ditches - several days' or even an entire week's sludge production can be lost as the result of sludge bulking in several hours. Effluent TSS may be less than 10 mg/L before and after bulking occurs, but may reach 1,000-2,000 mg/L while bulking. The operator has ample opportunity between bulking periods to collect more than enough samples to meet permit monitoring requirements and indicate a good effluent quality.

Another sampling procedure that can result in nonrepresentative monitoring is sometimes seen in fixed film facilities where performance degrades significantly during peak daytime loads. Samples collected from 6 a.m. to 10 a.m. may meet the required compositing criteria (e.g., three samples at 2-hour increments), but would probably indicate better than overall average effluent quality. Likewise, samples collected from noon to 4 p.m. may indicate worse than actual average effluent quality.

To verify good data or determine the magnitude of a performance problem, a comparison of expected vs. actual sludge production should be made during the CPE. This comparison has proven invaluable in conducting a CPE and is termed a Sludge Accountability Evaluation. A detailed example of this evaluation is presented.

a. Example Sludge Accountability Evaluation

A 44-L/s (1-mgd) oxidation ditch activated sludge plant is bring evaluated. The plant's NPDES discharge monitoring reports indicate that the plant is in compliance. Information collected during the CPE is as follows:

- The plant operator felt the final clarifier was not large enough to capture all the solids during high flows - he suggested that a flow equalization basin be constructed.
- The plant has 1 oxidation ditch, 2 final clarifiers, 1 chlorine contact tank, and 6 sludge drying beds.
- The plant has limited infiltration/inflow (I/I) and no significant industrial waste contribution. I/I occurs in the early spring, causing the highest average monthly flow to be about 20 percent greater than the annual average flow.
- The City Clerk reported that there were 3,520 taps that were billed quarterly.
- The plant does not have return sludge flow measurement. Two constant-speed return sludge pumps are available to return sludge to the oxidation ditch. Both pumps are being operated at full speed to "get the solids out of the clarifier and back to the oxidation ditch." The R/Q ratio was estimated to be greater than 500 percent by measuring the return sludge flow rate utilizing draw-down of the final clarifier. Return sludge flow can be reduced by adjusting a plug valve on the discharge side of the pump, and by operating 1 of the 2 pumps. It is difficult to operate the pump at lower flow rates because the valve plugs with rags.
- Excellent laboratory facilities were available and the operators run all tests required by the NPDES permit. These include tests for: plant influent and effluent BOD_5 and TSS; plant effluent residual chlorine; and fecal coliform. Oxidation ditch MLSS tests are run once per week along with a settling test in a graduated cylinder to determine SVI.
- The plant superintendent reported that he wasted sludge to his drying beds when he had trouble keeping the sludge in the final clarifiers.
- The population of the community was estimated by the Mayor to be about 8,500.
- Influent plant flow was checked by measuring the depth of flow in the Parshall flume and comparing the calculated flow to the flow indicator. The reading was within 10 percent of the measured flow.
- The plant superintendent said that he "filled up" all of his drying beds "about 10 times" last year. There are 6 beds, each measuring 100' x 50' x 18" deep.
- NPDES permit monitoring requirements and plant effluent limits are as follows:
- Plant performance data are shown in the table below:

Plant Loading Evaluation

Plant loadings should be verified by comparison to typical per capita contributions for domestic wastewater. Since industrial loadings can significantly effect this evaluation, plants where significant

	Permit Limits		Monitoring Requirements	
Parameter	30-day avg.	7-day avg.	Frequency	Sample Type*
Influent BOD_5	-	-	Monthly	Composite
Effluent BOD_5	30 mg/L	45 mg/L	Monthly	Composite
Influent TSS	-	-	Monthly	Composite
Effluent TSS	30 mg/L	45 mg/L	Monthly	Composite
Effluent pH	6.5-9	6.5-9	Weekly	Grab
Fecal Coliform	200 per 100 mL	400 per 100 mL	Monthly	Grab

* A composite sample is defined as being comprised of a minimum of 4 samples collected 2 hours apart with the individual sample volume being proportioned to plant flow.

Performance Data for Example Sludge Accountability Evaluation

	Raw				Final Effluent[3]	
Date	Flow, mgd[1]	BOD_5, mg/L[2]	TSS, mg/L[2]	BOD_5 Load, lb	BOD_5, mg/L[2]	TSS, mg/L[2]
6/84	0.791	276	290	1,820	8	10
7/84	0.762	281	205	1,785	7	12
8/84	0.781	270	232	1,758	5	11
9/84	0.720	274	190	1,645	7	12
10/84	0.759	251	237	1,589	4	9
11/84	0.747	225	241	1,402	9	10
12/84	0.715	231	187	1,377	7	9
1/85	0.729	197	215	1,198	6	9
2/85	0.761	263	217	1,669	4	10
3/85	0.813	201	245	1,363	7	14
4/85	0.938	173	198	1,353	11	18
5/85	0.880	197	220	1,446	9	16
Avg.	0.783	237	223	1,534	7	12

[1] Flow recorded daily.

[2] Based on one composite sample/montn. Composite sampling usually done on Thursday. Samples collected at 8:00 am, 9:00 am, 11:00 am, and 1:00 pm. Influent BOD_5 and TSS values may be high since this is the peak load period of the day.

[3] The operator reported the need for flow equalization since, during high flows, some solids were lost. No indication of solids loss is apparent in plant effluent data.

Source of Data: Plant NPDES Monitoring Records

industrial contributions are known to be present cannot be evaluated in this manner.

1. *Population Served* (assume 2.5 persons/tap).

(2.5 persons/tap) x (3.520 taps) = 8,800 people

Use average of reported population and estimated population:

(8,500 + 8,800) ÷ 2 = **8,650 people**

2. *Plant Flow Evaluation* (assume 100 gal/capita/d for typical domestic wastewater).

Projected plant flow = 8,650 x 100 = 865,000 gpd
Measured plant flow = **783,000 gpd**

Conclusion: measured plant flow appears to be within expected range - therefore use actual plant flow in evaluation.

3. *Organic Loading Evaluation* (assume 0.15-0.20 lb BOD_5/capita/d for typical domestic wastewater - use 0.17).

Projected plant organic load = 8,650 x 0.17
= **1,471 lb BOD_5/d**

Plant organic load from plant data = 1,534 lb BOD_5/d

Conclusion: plant BOD_5 data is higher than projected BOD but sampling is during peak load portions of the day - use projected organic load.

Calculated influent BOD_5:

(1,471) ÷ (8.34 x 0.783) = **225 mg/L**

Sludge Accountability Evaluation

1. Determine anticipated sludge production.

BOD_5 conc. removed = 225 - 7 = 218 mg/L

BOD_5 mass removed = 218 (0.783) (8.34)
= 1,424 lb BOD_5/d

From Table 2-7, expected lb TSS (sludge)/lb BOD_5 removed = 0.65 for an oxidation ditch. Therefore:

Expected sludge = 0.65 (1,424) (365)
= **337,990 lb/yr**

2. Estimate Accounted-For Sludge Wasted From Plant.

Effluent "Waste Sludge" = (0.783)(12)(8.34)(365)
= 28,602 lb/yr

Intentionally Wasted Sludge (operator said he filled sludge beds "about ten times" last year):

Sludge bed volume = (6 beds) (100') (50') (18"/12)
= 45,000 cu ft

Waste sludge volume = (10 times) (45,000) (7.48)
= 3,366,000 gal/yr

From Table 2-8, expected waste sludge concentration is 7,500 mg/L. (Assume that return sludge flow can be controlled within a reasonable range.) Therefore:

Wasted Sludge = 3.366 (7,500) (8.34)
= 210,543 lb/yr

Total Accounted-For Sludge = 28,602 + 210,543
= **239,145 lb/yr**

Complete Sludge Accountability Summary Sheet From Appendix D as Shown on Following Page

As shown in this example, the sludge accountability analysis indicates that the plant effluent data are probably not a reliable indicator of true plant performance. Effluent quality could have been quite good when samples were collected, yet periodic solids loss could have been occurring during the relatively infrequent effluent monitoring events. Use of the sludge accountability evaluation often provides significant insight to the CPE effort.

2.3.5.2 Projected Improved Performance

The plant performance that is achievable is initially estimated by evaluating the capability of major unit processes. This concept is schematically shown in Figure 2-1. If major unit processes are deficient in capacity, secondary treatment may not be achievable with the existing POTW (i.e., it is a Type 3 plant).

If the evaluation of major unit processes shows that the major facilities have adequate capacity, then an approach, like the CCP approach presented in Chapter 3 likely can be used to achieve improved POTW performance (i.e., it is a Type 1 or 2 plant). For plants of these types, all performance-limiting factors are considered as possible to correct with adequate training of the appropriate POTW personnel. The training is addressed toward the operational staff for improvements in plant process control and maintenance; toward the POTW administration for improvements in administrative policies and budget limitations; and toward both operators and administrators to achieve minor facility modifications. "Training" as used in this context describes activities whereby information is provided to facilitate understanding and facilitate implementation of corrective actions.

Once the plant's major unit process capability has been established and the performance-limiting factors have been identified and prioritized, the evaluator is in a position to assess the potential for improved performance. During this effort, the evaluator must assess the practicability and potential time frame necessary to address each identified factor. Additionally, it is necessary to project levels of effort, activities, time frame, and costs associated with implementation of activities to optimize existing facilities (e.g., by implementing a CPE). Projecting costs for modifying a Type 3 plant are beyond the scope of a CPE effort.

2.3.6 *Presentation to POTW Administrators and Staff*

Once the evaluator has completed the fieldwork for the CPE, an exit meeting should be held with the POTW administrators and staff. A presentation of preliminary CPE results should include brief descriptions of the following:

- Sludge Accountability Analysis
- Evaluation of major unit processes (Type 1, 2, or 3)
- Prioritized performance-limiting factors
- Plant performance potential

In general, it is desirable to present all findings at the exit meeting with local officials. This approach eliminates surprises when the CPE report is received and begins the cooperative approach necessary for any follow-up activities. In situations where administrative or staff factors are difficult to present, the evaluator must be sensitive and use communication skills to successfully present the results. Throughout the discussions, the evaluator must remember that the purpose of the CPE is to identify and describe facts to be used to improve the current situation, not to place blame for any past or current problems.

It should be made clear at the exit meeting that other factors likely will be identified during the conduct of any follow-up activities. These factors will also have to be addressed to achieve the desired performance. This understanding of the short-term CPE evaluation capabilities is often missed by local and regulatory officials, and efforts may be developed to address only the items prioritized during the CPE. The evaluator should stress that a commitment must be made to achieve the desired improved performance, not to addressing a "laundry list" of currently identified problems.

2.3.7 *CPE Report*

The objective of a CPE report is to summarize the CPE findings and conclusions. It is particularly important that the report be kept brief so that the maximum amount of resources are used for the evaluation rather than for preparing an all-inclusive report. The report should present the important CPE conclusions necessary to allow the decision-making officials to progress toward achieving desired performance from their facility. Eight to twelve typed pages are generally sufficient for the text of a CPE report. A brief example CPE report is presented in Appendix C. Typical contents are:

- Introduction
- Facility background
- Major unit process evaluation
- Performance-limiting factors
- Performance improvement activities
- Costs

As a minimum, the CPE report should be distributed to POTW administrators and key plant personnel. Further distribution of the report (e.g., to the design engineer or regulatory agencies) depends on the circumstances of the CPE, but should be done at the direction, or with the awareness, of local administrators.

Performance Monitoring/Sludge Accountability Summary Sheet (Example)

1. Sludge Accountability		**Item**
• Anticipated Sludge Production (see Table 2-7, note: unit production values include solids lost in plant effluent)	337,990 lb/yr	**1**
• Accounted-for Sludge		
- wasted intentionally	210,543 lb/yr	**2**
- effluent sludge	28,602 lb/yr	**3**
Total: **2** + **3**	239,145 lb/yr	**4**
• Unaccounted-for Sludge: **1** - **4**	98,845 lb/yr	**5**
5 ÷ 365	271 lb/d	**6**
• Unaccounted-for Sludge Percentage: 100 x **5** ÷ **1**	29.2 %	**7**
if -15 < **7** < 15 then not possible to conclude that a problem with sludge wasting exists.		
if **7** > 15 then problem with effluent monitoring indicated.	← **CONDITION FOUND**	
if **7** < -15 then may indicate organic loading greater than typical domestic (i.e., industrial loading).		
2. Performance Monitoring Assessment		
• Projected Actual Effluent TSS		
- recorded effluent TSS	12 mg/L	**8**
- projected increase in effluent TSS: **6** ÷ (8.34 x flow in mgd)	41 mg/L	**9**
- estimated actual increase in effluent TSS: **8** + **9**	53 mg/L	
• Projected Actual Effluent BOD$_5$		
- recorded effluent BOD$_5$	7 mg/L	**10**
- projected increase in effluent BOD$_5$: 0.5 x **9**	21 mg/L	**11**
- estimated actual increase in effluent BOD$_5$: **10** + **11**	28 mg/L	

2.3.7.1 Introduction

The introduction of the CPE report should cover the following topics:

- Reason(s) for the CPE
- Objectives of the CPE
- Plant effluent performance requirements

2.3.7.2 Facility Background

This section should include general information about the POTW that will serve as the reference basis for the remainder of the report. The following information should be included:

- POTW description (oxidation ditch, RBC, etc.)
- Design and current flows
- Age of plant and dates of upgrades
- Service population
- Significant industrial wastes
- Significant infiltration/inflow
- Unit processes diagram

2.3.7.3 Major Unit Process Evaluation

This section should include a description of the assessed plant type (Type 1, 2, or 3) and a summary of data sources for calculating current loading; for example, "current loadings were calculated using plant laboratory results for concentrations and plant flow records lowered by 10 percent to adjust for high calibration of flow recording equipment." Other significant evaluations should be included in this section, such as calibration of flow measuring devices, sludge accountability analysis, evaluation of loads from industrial contributors, etc.

Results should be presented for each major unit process (aerator, secondary clarifier, sludge handling processes). The evaluator may choose to present capabilities of other unit processes if these data are pertinent to assessing the POTW's treatment capability.

An effective method of presenting results of a plant's unit process evaluation relative to current and design loadings is the use of a *Performance Potential Graph*.

An example of this type of graph is shown in Figure 2-4. The plant's unit processes are listed in the left-hand column. Plant loadings, typically flow or BOD or both, are shown horizontally across the top of the graph. Current and design loadings are depicted by vertical dashed lines. Rated capabilities of the various unit processes are projected using horizontal bars.

Specific evaluation criteria are listed under each unit process. Assumptions for each set of calculations used to determine the values of the selected evaluation criteria are noted on the bottom of the graph. In addition, the value of the parameter used to project the unit's capability is shown.

The graph is time consuming to develop, but a great deal of clarity is provided to facility administrators and personnel when the plant's capabilities are thus depicted. It is important to note that the capabilities are not established using "typical" design values for unit process capacity. Judgment of the evaluator, each plant's unique circumstances, and experience with other similar facilities are factors that affect projections of the unit process capability to meet the plant's performance requirements.

As might be expected, rating a unit process capabilities less than at its "design capacity" is something that requires full awareness of the possible ramifications. A first question of some administrators is "Why didn't I get what I paid for?" Many reasons may exist, such as industrial loadings not anticipated in design, inaccurate loading assumptions, changed criteria for capabilities of unit processes based on experience, etc. As such, the evaluator who chooses to use the Performance Potential Graph must be prepared to support the projections. Despite the potential ramifications, the effectiveness of the graph in presenting CPE results makes attempts to present information in this manner worthwhile.

2.3.7.4 Performance-Limiting Factors

Factors limiting performance that were identified during the CPE should be listed. The more serious factors (those receiving "A" or "B" ratings) are listed in order of priority and short, one- or two-paragraph explanations of each factor are included. Factors receiving a "C" rating are normally also listed. Often it is appropriate to summarize factors not identified as performance-limiting (i.e., areas where the POTW was meeting or exceeding expectations) in this section of the report.

2.3.7.5 Performance Improvement Activities

Activities required to achieve required plant performance are briefly discussed. If a CCP activity could improve performance, this should be stated. If facility modifications are indicated (i.e., Type 3 plant), then a recommendation for a more detailed evaluation of treatment alternatives should be recommended. Any additional benefits, such as reduction in energy consumption, improved safety, etc., should also be indicated.

2.3.7.6 Costs

Costs associated with follow-up activities should be projected as accurately as possible. Ranges of costs can be used if an evaluator does not feel comfortable projecting specific dollar amounts. Each cost projected should be indicated as a "one-time" or "annual" cost. Costs for a CCP facilitator (consultant) or for a piping modification are examples of "one-time" costs. Increased sludge handling and electrical or chemical costs are examples of "annual" costs.

2.3.8 Example CPE

A 52.6-L/s (1.2-mgd) oxidation ditch serves a primarily residential community with a population of 8,500. The City Council was notified by the State Health Department that the City's self-monitoring reports indicated the City is not meeting its NPDES permit requirements of 30 mg/L (30-day average) for BOD_5 and TSS.

After researching several alternatives, the Public Works Director recommended to the City Council that a CPE be conducted to determine the causes of their performance problem and provide direction in selecting corrective actions. A consultant who specializes in conducting CPEs was subsequently hired.

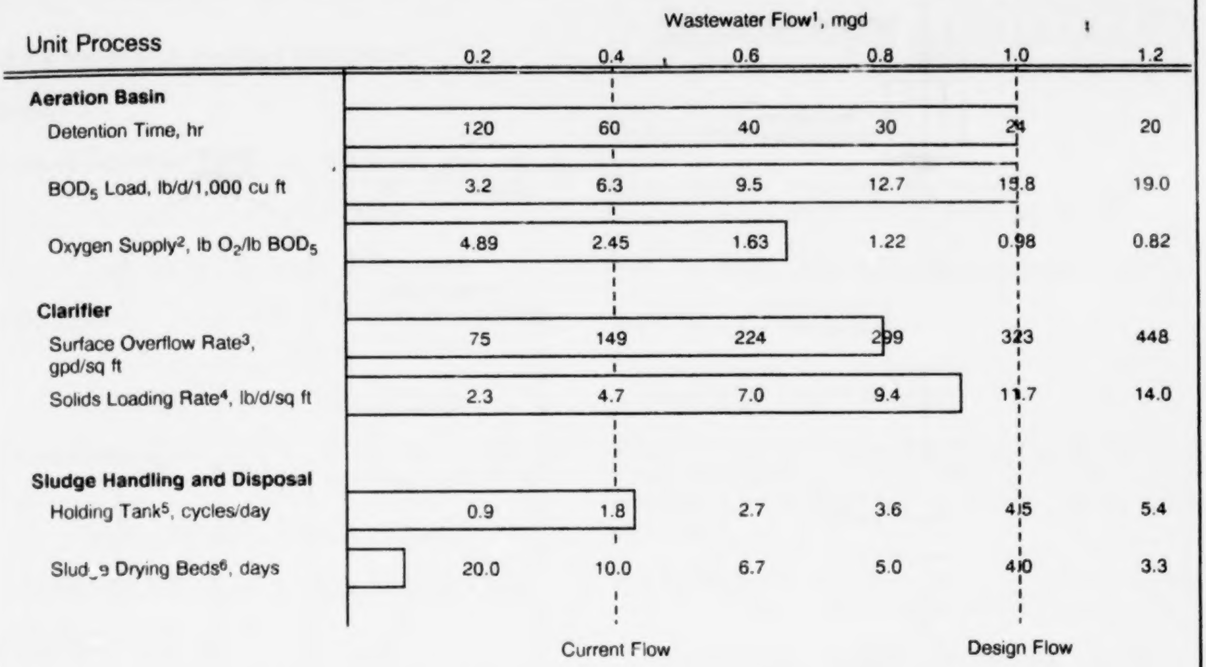
2.3.8.1 Plant Data

A flow diagram is presented in Figure 2-5. The following data were extracted from the completed data collection forms as presented in Appendix D.

DESIGN DATA

Design Flow:	52.6 L/s (1.2 mgd)
Hydraulic Capacity:	131.5 L/s (3.0 mgd)
Organic Loading:	900 kg (2,000 lb) BOD_5/d 900 kg (2,000 lb) TSS/d
Preliminary Treatment:	Mechanical Bar Screen, Aerated Grit Chamber
Flow Measurement:	Parshall Flume, Sonic Level Sensor, Strip Chart Recorder
Oxidation Ditch:	Volume - 4,500 m^3 (160,000 cu ft) O_2 Transfer - Brush Rotors rated at 1,800 kg (4,000 lb)/d @ 38°C (100°F) with 2.0 mg/L residual DO
Final Clarifiers:	Number - 2 with Center Feed and Peripheral Weirs

Figure 2-4. Example performance potential graph.



Unit Process	0.2	0.4	0.6	0.8	1.0	1.2
Aeration Basin						
Detention Time, hr	120	60	40	30	24	20
BOD_5 Load, lb/d/1,000 cu ft	3.2	6.3	9.5	12.7	15.8	19.0
Oxygen Supply[2], lb O_2/lb BOD_5	4.89	2.45	1.63	1.22	0.98	0.82
Clarifier						
Surface Overflow Rate[3], gpd/sq ft	75	149	224	299	323	448
Solids Loading Rate[4], lb/d/sq ft	2.3	4.7	7.0	9.4	11.7	14.0
Sludge Handling and Disposal						
Holding Tank[5], cycles/day	0.9	1.8	2.7	3.6	4.5	5.4
Sludge Drying Beds[6], days	20.0	10.0	6.7	5.0	4.0	3.3

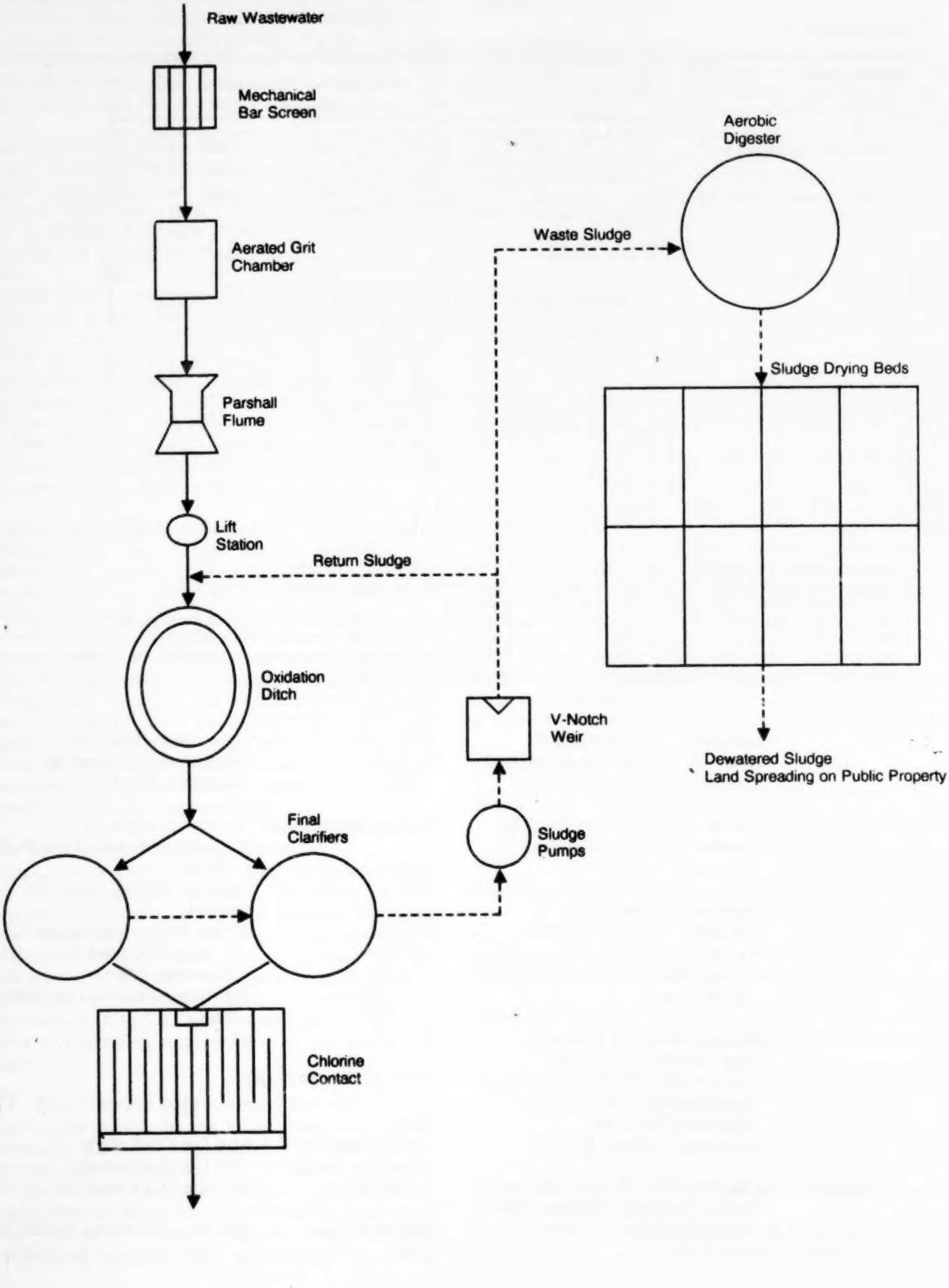
[1] Assume average influent BOD concentration of 254 mg/L based on current plant records.
[2] Assume 83 lb/hr oxygen transfer rate per manufacturer's literature and 1.5 lb O_2 required/lb BOD applied.
[3] Use maximum overflow rate of 600 gpd/sq ft at 2:1 diurnal peaking.
[4] Assume 2,500 mg/L MLSS; 50% R/Q; consider 2:1 peaking; and maximum solids loading of 20 lb/d/sq ft; includes R + Q.
[5] Waste MLSS from aeration basin at 2,500 mg/L; assume sludge production ratio = 0.65 lb TSS/lb BOD_R; Influent BOD_5 = 254 mg/L; Effluent BOD_5 = 10 mg/L; 14,000-gal holding tank; 2 cycles per day maximum with existing staff.
[6] Waste from holding tank at 7,500 mg/L; 9-inch pour; 21-day turnover time required.

	Diameter - 10.7 m (35.0 ft) Area - 90 m^2 (962 sq ft) each Sidewater Depth - 2.7 m (9.0 ft) Center Depth - 3.1 m (10.5 ft) Clarifier Scraper to Center Hopper
Disinfection:	Number of Chlorinators - 2 Capacity - 113 kg (250 lb)/d each) Contact Basin - 142 m^3 (37,500 gal)
Sludge Return:	Number of Vortex Pumps - 2 Flow Control - 1.9-5.7 m^3 (500-1,500 gal)/min Measurement - 90° V-notch Weir w/o Recorder Sampling - Manual @ Weir
Aerobic Digester:	Volume - 680 m^3 (220,000 gal) Sludge Removal - Bottom Pipe to Drying Beds
	Supernatant Removal - Muliple-Port Drawoff to Oxidation Ditch
Sludge Drying Beds:	Number of Beds - 8 Size - 18.2 m x 45.0 m (60 ft x 150 ft) Summer Drying Time - 3 weeks Winter Drying Eliminated - Storage Required for December-March Subnatant Returned to Head of Plant

CURRENT LOADING

Flow:	
Annual Average	41.6 L/s (0.95 mgd)
Minimum Month	37.5 L/s (0.855 mgd)
Peak Month	50.0 L/s (1.14 mgd)
Influent BOD_5:	190 mg/L or 680 kg (1,500 lb)/d

Figure 2-5. Flow diagram of POTW in example CPE.



Raw Wastewater
Mechanical Bar Screen
Aerated Grit Chamber
Parshall Flume
Lift Station
Return Sludge
Oxidation Ditch
Final Clarifiers
Chlorine Contact
Waste Sludge
Aerobic Digester
Sludge Drying Beds
V-Notch Weir
Sludge Pumps
Dewatered Sludge Land Spreading on Public Property

Influent TSS: 205 mg/L or 740 kg (1,600 lb)/d

2.3.8.2 Major Unit Process Evaluation

Aerator

Hydraulic Detention Time: [(160,000 cu ft x 7.48) ÷ (950,000 gpd)] x 24 = 30 hr

From Table 2-2, Score = 10 points

BOD_5 Loading: [(1,500 lb/d) ÷ (160,000 cu ft)] x 1,000 = 9.4 lb/d/1,000 cu ft

From Table 2-2, Score = 10 points

Oxygen Availability: (4,000 lb O_2/d) ÷ (1,500 lb BOD_5/d) = 2.6 lb O_2/lb BOD_5

From Table 2-2, Score = 10 points

Aerator Subtotal = 10 + 10 + 10 = 30 points

Secondary Clarifier

Configuration: Circular With Weirs on Wall

From Table 2-4, Score = 5 points

Surface Overflow Rate: (1,140,000 gpd) ÷ (1,924 sq ft) = 592 gpd/sq ft

From Table 2-4, Score = 7 points

Depth at Weirs: 9.0 ft

From Table 2-4, Score = -3 points

Return Sludge Removal: Scraped to Center Hopper

From Table 2-4, Score = 8 points

Return Sludge Control:

From Table 2-5, Typical Range is 50-100% of Influent Wastewater Flow.

Desired Range = (50% x 0.855 mgd) to (100% x 1.14 mgd) = 0.43-1.14 mgd

Actual Range = (500 gpm x 1,440 x 10^{-6}) to (1,500 gpm x 1, 440 x 10^{-6}) = 0.72-2.16 mgd

Actual Return Sludge Control is 59% (0.72 to 1.14 mgd) of Desired Range.

Return Sludge Measurement Provided.

From Table 2-4, Score = 5 points

Sec. Clarifier Subtotal = 5 + 7 - 3 + 8 + 5
= 22 points

Sludge Handling Capability

Controllability: Waste Volume Manually Calculated
Waste Stream Manually Sampled

From Table 2-6, Score = 2 points

Capacity:

a. Expected Sludge Production

Effluent BOD_5 achievable is assumed value for a well operated oxidation ditch facility. Unit sludge production, from Table 2-7 is 0.65 lb TSS/lb BOD_5 removed.

BOD_5 Removed = (Influent BOD_5 - Effluent BOD_5 Achievable) x Flow

= (190 mg/L - 15 mg/L) x (0.95 mgd) x (8.34)
= 1,385 lb/d

Expected Sludge Mass = (0.65 lb TSS/lb BOD_5) x (1,385 lb BOD_5/d)
= 900 lb TSS/d

Expected Sludge Concentration, From Table 2-8: 7,500 mg/L.

Expected Sludge Volume = (900 lb/d) ÷ (7,500 mg/L x 8.34 x 10^{-6})
= 14,400 gpd

Increase by 25 percent to allow operation flexibility:

Expected Sludge Volume = 1.25 x 14,400
= 18,000 gpd

b. Percentage of Expected Sludge Production Each Process Can Handle

1. Aerobic Digester

From Table 2-9, standard for evaluating aerobic digesters is a hydraulic detention time of 15 days.

Sludge Volume Existing Digester Can Handle
= (220,000 gal) ÷ (15 days) = 14,670 gpd

Percentage of Expected Sludge Production
= (14,670 gpd) ÷ (18,000 gpd)
= 81 percent

2. Drying Beds

From Table 2-9, the standard for evaluating drying beds is the worst season turnover time as demonstrated by past experience. Essentially, no drying is experienced from December through March so that beds operate only as storage during that period. Storage volume required must first be calculated.

Digester Hydraulic Detention Time (HDT)
= Digester Volume/Sludge Volume

HDT = (220,000 gal) ÷ (18,000 gpd) = 12.2 days

From Table 2-10, for HDT = 12 days, total solids reduction of 14% and output solids concentration of about 13,000 mg/l is expected.

Sludge to Drying Beds = (900 lb TSS/d) x (1.00 - 0.14) x (1.25 flex. factor)
= 967 lb/d

Sludge Volume = (967 lb/d) ÷ (13,000 mg/L x 8.34 x 10^{-6})
= 8,919 gpd

Storage Capacity of Existing Beds = (8) x (60 ft x 150 ft x 1.5 ft)
= 108,000 cu ft

Storage Capacity Available = (108,000 cu ft x 7.48) ÷ (8,919 gpd)
= 91 days

Storage Capacity Required = 31 (December)
31 (January)
28 (February)
30 (March)
121 days

Drying bed capacity is available for 8 months of the year, but only 75% (91 ÷ 121) of required storage capacity is available during the winter 4 months.

Existing Drying Bed Adequacy = Worst Case - Use Winter Capacity of 75 percent

3. Hauling

From discussions with the POTW staff and administrators, "Hauling dried sludge is not a problem. If we have to, we can get the street crew down to the plant to help out."

Hauling Adequacy = 100 percent

4. Land Application

From discussions with the POTW staff and administrators, "If we can get it through the beds, we can get rid of it. We can go to the landfill if we have to."

Land Application Adequacy = 100 percent

From the capacity evaluation, the drying beds are the "weakest link" at 75 percent capacity.

From Table 2-6, Score = 0 points

Sludge Handling Capability Subtotal = 2 + 0
= 2 points

Scores for each major unit process are presented in Table 2-11.

The data in Table 2-11 indicate that the aerator points are sufficient to receive a Type 1 rating. However, the points scored for the secondary clarifier, sludge handling capability, and the total plant are only sufficient for a Type 2 rating. Therefore, the overall plant rating is Type 2. This rating indicates that improvement in plant performance without any upgrade of major processes is likely.

2.3.8.3 Performance-Limiting Factors

The following performance-limiting factors were identified during the CPE and given rankings of "A" or "B." Further prioritization of these identified factors was also completed, as indicated by the number assigned to each factor.

1. *Operator Application of Concepts and Testing to Process Control ("A")*

Less sludge was wasted than was produced on a routine basis. Excess sludge periodically bulked from the final clarifiers. Mixed liquor concentrations were monitored routinely, but the concept of controlling total sludge mass at a desired level was not implemented. Operation of return sludge flow at excessively high rates, typically 150-200 percent of wastewater flow, contributed to solids loss.

2. *Sludge Wasting Capability ("B")*

An undersized digester and drying beds that do not provide adequate sludge disposal capability during winter months result in inadequate sludge wasting capacity.

3. *Improper Technical Guidance ("B")*

The above process control and inadequate sludge disposal situation continued despite annual plant inspections by the State district engineer. "Periodic solids loss" was given the same emphasis in the annual inspection reports as plant housekeeping, timely submittal of monitoring reports, leveling and

Table 2-25. Suspended Growth Major Unit Process Capacity Evaluation for Example CPE

	Points Scored	Points Required*		
		Type 1	Type 2	Type 3
Aeration Basin	30	13-30	0-12	<0
Secondary Clarifier	24	25-55	0-24	<0
Sludge Handling	2	10-30	0-9	<0
Total	56	60-115	20-59	<20

* Each unit process as well as the overall points must fall in the designated range for the plant to achieve the Type 1 or 2 rating.

cleaning of clarifier weirs, and other items far removed from the true performance-limiting problems and potential solutions.

4. Performance Monitoring ("B")
Performance monitoring samples were collected routinely in the morning hours. Periods when solids loss occurred from the clarifiers were generally in the afternoon.

5. Familiarity With Plant Needs ("B")
Administrators were not familiar enough with the plant requirements for performance and operations to adequately make decisions on the plant budget yet they did not allow the plant superintendent to have input to the budgeting process.

6. Process Controllability ("B")
Oversized return activated sludge pumps were provided in the plant design. This promoted poor operation with excessively high return flows and would require a modification to improve process control.

2.3.8.4 Performance Improvement Activities

The most serious of the performance-limiting factors identified were process control oriented. The evaluation of major unit processes resulted in a Type 2 rating because of marginal, but not drastically deficient, sludge handling capability. The POTW appears to be a good candidate for improved performance through implementation of a CCP. This recommendation should be presented to the City Council. Continual compliance will depend on the ability to dispose of adequate quantities of waste sludge. Documentation of improved performance may be difficult because existing monitoring data do not reflect true past effluent quality.

2.3.9 CPE Worksheets

Worksheets for evaluating POTW capability are presented in Appendices L through P. These worksheets can be used to assess the capability of existing major unit processes (i.e., aerator, to perform secondary clarifier, and sludge handling system) and to determine whether the POTW is a Type 1, 2, or 3 plant. It should be noted that these worksheets simplify the steps presented in this chapter. However, this simplification cannot be substituted for the judgment of the CPE evaluator in assessing a particular facility.

2.3.10 CPE Results

The success of conducting CPE activities can be measured by POTW administrators selecting an approach and implementing activities to achieve the required performance from their wastewater treatment facility. If definite followup activities are not initiated within a reasonable time frame, the objectives of conducting a CPE have not been achieved.

2.4 Personnel Capabilities for Conducting CPEs

Persons responsible for conducting CPEs should have a knowledge of wastewater treatment, including the following areas:

- Regulatory requirements
- Process control
- Process design
- Sampling
- Laboratory testing
- Microbiology
- Hydraulic principles
- Operator training
- Wastewater facility budgeting
- Safety
- Maintenance
- Management

Consulting engineers who routinely work with POTW design and start-up, and regulatory agency personnel with experience in evaluating wastewater treatment facilities, represent the types of personnel with adequate backgrounds to conduct CPEs.

2.5 Estimating CPE Costs

The cost of conducting a CPE depends on the size and type of facility. Activated sludge plants tend to be more complex than trickling filter plants or other fixed film facilities. Guidelines for estimating CPE costs and person-days are presented in Table 2-26. These estimates are for contracting with a consultant who normally performs this type of service. The cost to a community for conducting a CPE with municipal employees would probably be less than the amounts shown in Table 2-26. However, municipal employees may not have the necessary qualifications or may be too close to the existing operation to be able to perform a truly objective evaluation.

Table 2-26. Typical Costs for Conducting CPEs[a]

Type and Size of Facility	Person-Days Onsite	Typical Cost (1988 $)
Suspended Growth[b,c]		
<9 L/s (0.2 mgd)	2	2,000-5,000
9-88 L/s (0.2-2 mgd)	5	3,000-12,000
88-440 L/s (2-10 mgd)	7	4,000-18,000
Fixed Film[d]		
<22 L/s (0.5 mgd)	2	2,000-5,000
22-440 L/s (0.5-10 mgd)	5	3,000-12,000
Stabilization Ponds	2	2,000-5,000

[a] For contract consultant.

[b] Includes all variations of activated sludge.

[c] ABF systems, which combine suspended and fixed growth, require an effort similar to activated sludge.

[d] Includes trickling filters with both plastic and rock media as well as RBCs.

2.6 References

When an NTIS number is cited in a reference, that reference is available from:

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
(703) 487-4650

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Chapter 3

Conducting Composite Correction Programs

3.1 Objective

The objective of a Composite Correction Program (CCP) is to improve the performance of an existing POTW (1). If the results of a Comprehensive Performance Evaluation (CPE) indicate a POTW is a Type 1 plant (see Figure 2-1), then the existing major unit processes have been determined to be adequate to meet current treatment requirements. For Type 1 facilities, the CCP focuses on systematically addressing performance-limiting factors to achieve the desired effluent quality. This can be done without major plant modifications (2).

For Type 2 plants, the existing major unit processes have been determined to be marginal but improved performance is likely through the use of a CCP, and the POTW may or may not meet performance objectives without major facility modifications. For these plants, the CCP focuses on clearly defining the optimum capability of existing facilities. Even if the CCP does not achieve the desired effluent quality, unit process deficiencies will be identified and plant administrators can be confident in pursuing the facility modifications indicated.

For Type 3 plants, major construction is often indicated and a more comprehensive study is warranted. A study of this type could look at long-term needs, treatment alternatives, potential location changes, and financing mechanisms. Chapter 4 provides alternatives for making facility modifications at existing facilities where specific design deficiencies have been identified. Typically, a CCP would not be implemented at a Type 3 facility until adequate modifications have been completed.

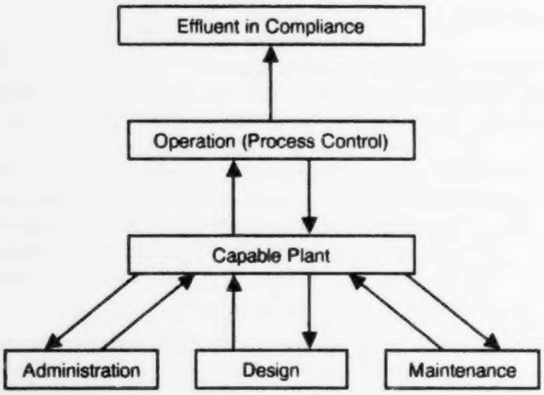
3.2 CCP Methodology

The methodology for conducting a CCP is a combination of: 1) implementing activities that support process requirements; and 2) systematically training the staff and administrators responsible for wastewater treatment (2-4).

3.2.1 CPE Results

The basis for implementation and training efforts is the prioritized list of performance-limiting factors that was developed during the CPE (see Section 2.2.1.3). The list provides a plant-specific outline of activities that must be addressed during the CCP. It is important to note, however, that performance-limiting factors not identified in a CPE often become apparent during conduct of the CCP and must be addressed to achieve the desired level of performance (3).

Figure 3-1. Relationship of performance-limiting factors to achieving a performance goal.



3.2.2 Process Control Basis

The areas in which performance-limiting factors have been broadly grouped (administration, design, operation, and maintenance) are all important in that a factor in any one of these areas can individually cause poor performance. However, when implementing a CCP, the relationship of these areas to achieving the goal of an effluent in compliance must be understood. Administration, design, and maintenance activities all lead to a plant physically capable of achieving desired performance. It is the operation, or more specifically the process control activities, that take a physically capable plant and produce adequately treated wastewater, as indicated in Figure 3-1. By focusing on the needs of the biological treatment process, as established through process control efforts, priorities for changes to achieve improved performance are thus developed.

For example, if good performance in an extended aeration activated sludge plant cannot be maintained because bulky sludge has developed as a result of inadequate oxygen transfer capability, better performance requires meeting the oxygen deficiency (5). In this case, limitations in meeting process needs (inadequate DO) establish a high priority for design changes (i.e., oxygen transfer equipment). This example illustrates how the process control basis can be used to prioritize improvements in physical facilities. Proposed improvements must alleviate a deficiency in the existing "incapable plant," as identified by process requirements, so that progress toward the performance goal can be pursued. In this way the most direct approach to improve performance is implemented. Nonperformance-related improvements can be delayed properly until the plant has achieved the treatment objective for which it is intended.

3.2.3 Long-Term Involvement

Implementation of a CCP is a long-term effort, typically involving one year, for several reasons.

- *Greater effectiveness of repetitive training techniques.* Operator and administrator training can be conducted under a variety of actual operating (e.g., sasonal) and administrative experiences. Time is also necessary for the staff to develop confidence in new techniques.
- *Inherently long response times associated with making changes and achieving stability in biological systems.* Biological systems typically respond slowly to process control adjustments that affect the environment in which the microorganism population lives. New environmental conditions eventually result in changes in the relative numbers of different microorganisms. For example, for activated sludge systems, some changes can be accomplished in the period of three to five MCRTs, but it is not uncommon for some changes to take weeks and even several months before desired shifts in microorganism populations are accomplished (6).
- *Time required to make physical and procedural changes.* This is especially true for those changes requiring financial expenditures where administrative (e.g., city council) approval is necessary.
- *Attitude of staff.* If the staff is not supportive of the CCP approach, the CCP will require additional effort and may have to include some personnel changes to be successful.
- *Time required for identification and elimination of any additional performance-limiting factors that may be found during the CCP.*

3.3 CCP Activities

3.3.1 General

This section presents techniques that have been successfully used in implementing CCPs. The methods presented should not be considered as the only workable methods, since experience has shown that no single approach will work at every POTW (7). The concept of correcting performance-limiting factors, until the desired POTW performance is achieved, must remain the controlling guidance when implementing a CCP. Details of implementation are, of necessity, site-specific and should be left to the individual implementing the CCP.

The individual that implements a CCP is called a facilitator. This individual is typically an "outsider" and accomplishes the CCP objectives utilizing periods of on-site involvement interspersed with off-site limited involvement. The facilitator assumes a leadership role in making process control decisions, assigning responsibilities, training POTW staff, and checking progress. When not onsite, POTW personnel are responsible for this leadership and the CCP facilitator monitors their progress as well as the process control and performance of the plant.

The following tools have been successfully used in implementing a CCP:

- *Telephone calls* to routinely monitor CCP progress. Routine telephone contact can be used to train and encourage POTW personnel concerning their responsibility for making critical plant observations, interpreting data, and summarizing important indicators and conclusions. The effectiveness of telephone calls is limited in that the CCP facilitator must rely on observations of the POTW personnel rather than his/her own. To ensure common understanding of the telephone conversations, the CCP facilitator should always summarize important points, decisions that have been reached, and actions to be taken subsequent to the call. Both the CCP facilitator and POTW personnel should keep written phone logs.
- *Site visits* to verify or clarify plant status, initiate major process control changes, test completed facility modifications, provide onsite operator training, and report progress to POTW administrators. Specific dates for site visits should be scheduled as indicated by the plant status and training requirements.
- *Written reports* to promote clarity and continuity. Development of written reports depletes funds available for action-oriented work by both the POTW staff and the CCP facilitator; therefore, only concise status reports are recommended. Short (1-page) written summaries should also be prepared for each facility modification. Initially, these may be prepared by the CCP facilitator, but this responsibility should ultimately be transferred to the POTW staff.

- *Final CCP report* to summarize activities. Since all major recommendations should have been implemented during the CCP, only current status of the POTW performance should be presented in this report.

The approach of interspersing on-site with off-site involvement is illustrated in Figure 3-2. As the CCP progresses, fewer site visits and telephone calls will typically be necessary. This is in line with the transfer of responsibility to the permanent POTW staff. Typical levels of effort required by CCP facilitators are presented in Table 3-1. For any POTW, the level of effort is dependent on the specific performance-limiting factors.

3.3.2 Initial Site Visit

The working relationship between the CCP facilitator and the POTW staff and administration is established during the first site visit. A good working relationship - based on mutual respect, communication, and understanding of the CCP - greatly enhances the potential for success.

3.3.2.1 CPE Results

A CCP is often implemented by individuals more experienced in identifying and correcting factors limiting POTW performance than those who conducted the CPE. During the initial site visit, the CCP facilitator should allow time to confirm and/or modify the original performance-limiting factors identified in the CPE. Time to assess the Type 1 or 2 "rating" of the POTW should also be allowed.

The initial site visit is used to begin activities for addressing all major performance-limiting factors (rated "A" or "B" in the CPE). The process control focus of the CCP activities should be made apparent during this visit. Existing process control testing should be reviewed and modified so that all necessary process control elements are adequately monitored. Sampling frequency and location, collection procedures, and laboratory analyses should be reviewed and, if necessary, standardized so that data collected can be used for evaluating progress. New or modified sampling or analyses procedures should be demonstrated by the CCP facilitator and then performed by plant personnel under the supervision of the CCP facilitator.

3.3.2.2 Monitoring Equipment

Any needed sampling or testing equipment should be obtained as quickly as possible. Rental or "loaner" equiupment should be made available immediately. The CCP facilitator should assist the POTW personnel in obtaining administrative approvals.

3.3.2.3 Process Control Summaries

The CCP facilitator should, with the help of plant personnel, draft a precise summary form for process control parameters and performance monitoring results. Monthly records are often available, but monthly data are too infrequent to allow timely process control adjustments. POTW personnel should provide data from the summaries to the CCP facilitator throughout the CCP. Often, weekly summaries of data are used. However, if computer capability is available, electronic transfer of data can be used to allow daily data exchange.

In small plants, where process control and monitoring activities are not conducted on a daily basis, a single page can often be used to record results. A sample process control form for a small plant used both for in-plant records and as a summary sent to the CCP facilitator is shown in Figure 3-3. Terms used in this figure are defined in Table 3-2.

3.3.2.4 Process Control Adjustments

The CCP facilitator should begin directing process control adjustments during the site visit. Where process control adjustments are grossly out of line (e.g., 300 percent estimated return sludge flows), the CCP facilitator should direct changes toward more reasonable values. Fine tuning of process control procedures and training of the POTW staff cannot legitimately progress until this first level of effort is initiated.

When implementing major changes in process control adjustments, the facilitator must be very aware of the potential adverse impact on the POTW operators' morale. All recommendations for process control changes should be thoroughly explained prior to implementation. Even with this approach, a CCP facilitator should not expect to obtain immediate support from POTW personnel. A response such as "well, let's try it then and see" is often the best that can be expected. Some changes may have to be made with only the degree of consensus expressed by the statement: "I don't think it'll work, but we can try it."

3.3.2.5 Minor Design Changes

Any minor design changes identified as necessary by the CPE and confirmed by the CCP facilitator should be initiated during the site visit. Some design changes often require significant amounts of time for approvals, delivery of parts or equipment, or construction. It is necessary, therefore, to initiate changes as soon as needs are identified so that their effect can be evaluated during the majority of the CCP.

3.3.2.6 Action Lists

An important aspect of a CCP is implementation of activities to improve plant performance. As such, it is helpful to "inventory" the action items to be accomplished. A summary of this inventory is developed and updated throughout the CCP by the CCP facilitator. The summary is distributed to the plant staff and administration. An example format for an action list is shown in Figure 3-4.

Figure 3-2. Typical scheduling of CCP activities.

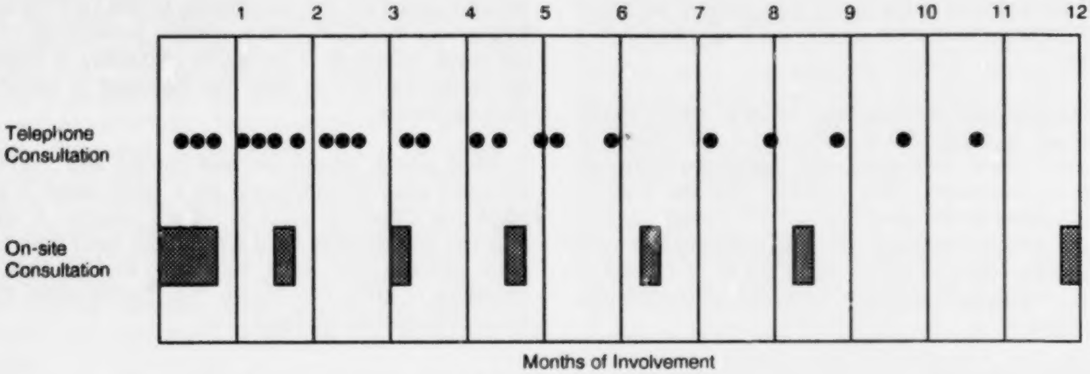


Table 3-1. Typical CCP Facilitator Involvement

Facility Size and Type*	Initial Site Visit	Telephone Consultation number/week		Additional Site Visits
	days	initial	end	days
Suspended Growth:				
44 L/s (1 mgd)	3-5	2-6	2-4	4-12
440 L/s (10 mgd)	4-10	3-8	2-4	6-20
Fixed Film:				
44 L/s (1 mgd)	2-5	1-3	1-4	3-8
440 L/s (10 mgd)	4-10	2-3	1-4	5-12

* Suspended growth facilities have greater process control flexibility and typically require a greater level of effort by the CCP facilitator.

3.3.3 Improving Design Performance-Limiting Factors

The performance of Type 1 and 2 POTWs can often be improved by making modifications or additions to the original design. A detailed discussion of facility modifications that can be used to improve plant performance is presented in Chapter 4. Only the conceptual approach to improving design performance-limiting factors will be presented here.

3.3.3.1 Identification and Justification

Initially, proper identification of a design perfor-mance-limiting factor is required. CPE results or findings during the conduct of a CCP are excellent methods to identify design limitations. Once design factors have been identified, the process of selecting facility modification alternatives for implementation can begin. An indexed guide is presented in Chapter 4 (Table 4-1) to assist in evaluating alternatives.

The CCP facilitator and POTW personnel must be able to justify each proposed modification based on the resulting increased performance capability that the modification will provide. A sound basis is to relate design modifications to the items needed to provide a capable plant such that process control objectives can be met (see Figure 3-1). The degree of justification required usually varies with the associated costs and specific plant circumstances. For example, little justification may be required to add a sampling tap in a sludge line. Whereas justification for modifications to the aeration basin to allow use of several modes of the activated sludge process would require much more emphasis. Additionally, extensive justification may be required for a facility where sewer rates are high and have recently been raised, yet there is no money available for an identified modification.

3.3.3.2 Implementation

The CCP facilitator should ensure that each modification is formally documented in writing. This documentation is more valuable in terms of training and commitment if it is completed by POTW personnel. It should include:

- Purpose of the proposed change (Identification/Justification)
- Detailed description of the change
- Quantitative criteria for evaluating success or failure of the change
- Individual(s) responsible for completing the change
- Cost estimate
- Anticipated improvement in plant performance
- Schedule

Another role of the CCP facilitator is to assist POTW personnel in understanding and implementing their responsibility in regard to the modification. Ideally, the CCP facilitator should be a technical and managerial reference throughout the implementation of the modification, and the POTW staff should have, or develop, the technical expertise, available time, and motivation to complete the modification. If there is a breakdown in completing assigned responsibilities, the CCP facilitator must become more aggressive in assuring completion of the modification.

3.3.3.3 Assessment

Following completion of a facility modification, the CCP facilitator should ensure that an evaluation of the

Figure 3-3. Sample process control and performance monitoring program form for a small plant.

PROCESS CONTROL SUMMARY

DATE ________
TIME ________
INITIALS ________

OPERATIONAL OBJECTIVES:

TSU ________ DO ________ $SSC_{60(min)}$ ________
RSP ________ DC_{min} ________ DC_{max} ________

RSP - lowest possible setting without plugging

PROCESS CONTROL TEST INFORMATION:

TIME (min.)	SSV (cc/L)	SSC (%)
0	1,000	
5		
30		
60		

ATC ________ RSC ________ CSC ________
DC ________ DOB ________ TEMP ________ °C
DO ________ FLOW ________

WASTING INFORMATION:

ASU = ATC x 264,000 = ________ ASU

CSU = CSC x 37,700 = ________ CSU

SDR = ASU ÷ CSU = ________

RSP = 100 x ATC ÷ (RSC - ATC) = ________ %

Current TSU = ASU + CSU = ________ TSU

Objective WSU = Current ASU - Objective TSU = ________ - ________ = ________ WSU

WSU ÷ WSCE = ________ ÷ ________ = ________ Gallons Needed to Waste

Gallons ÷ Gallons per Inch = ________ ÷ ________ = ________ Inches Estimated to Waste

Gallons per Inch	Actual Inches	Gallons	Actual WSC, %	WSU, Gal x %
306				
306				
306				
			Total Actual WSU	

ULTIMATE DISPOSAL INFORMATION:

DATE ________
Gal/Load ________ LOADS ________
Total Gals ________
Avg. UDC ________
App. Rate (Gal/Acre) ________

PLANT MONITORING INFORMATION:

DATE ________
Inf. BOD_5 ________ Eff. BOD_5 ________
Inf. TSS ________ Eff. TSS ________
MLSS ________ RATIO ________
Eff. FC ________

NOTES:

Table 3-2. Acronyms Used in Figure 3-3

Term	Definition	Calculation
Operational Objectives		
TSU	Total Sludge Units	ASU + CSU
DO	Dissolved Oxygen	
SSC_{60}	Settled Sludge Concentration in 60 Minutes	$1{,}000 \times ATC \div SSV_{60}$
RSP	Return Sludge Percentage	$100 \times ATC \div (RSC - ATC)$
DC	Digester Concentration	Centrifuge Spin
Process Control Test Information		
SSV	Settled Sludge Volume	cc/L from Mallory Settleometer
ATC	Aeration Tank Concentration	Centrifuge Spin
RSC	Return Sludge Concentration	Centrifuge Spin
CSC	Clarifier Sludge Concentration	Centrifuge Spin of Clarifier Core Sample
DOB	Depth of Sludge Blanket in Clarifier	
Wasting Information		
ASU	Aerator Sludge Units	Total Aeration Tank Volume x ATC
CSU	Clarifier Sludge Units	Total Clarifier Tank Volume x CSC
SDR	Sludge Distribution Ratio	ASU ÷ CSU
WSU	Waste Sludge Units	WSC x Waste Flow
WSCE	Estimated Waste Sludge Concentration	
Gallons per Inch	Incremental Volume of Waste Receiving Tank	
Ultimate Disposal Information		
UDC	Ultimate Disposal Concentration	Centrifuge Spin
Plant Monitoring Information		
MLSS	Mixed Liquor Suspended Solids Concentration	
Ratio		MLSS ÷ % Centrifuge Spin (mg/L per %)
FC	Fecal Coliform	# per 100 mL

improved POTW capability is completed and documented. This assessment should compare the quantitative criteria established for the project with the capability of the actual modification. A short summary (1-2 pages) is helpful in informing and maintaining support from POTW personnel and administrators.

3.3.4 Improving Maintenance Performance-Limiting Factors

Plant maintenance can generally be improved in nearly all POTWs, but it is a significant performance-limiting factor in only a small percentage of plants (1,4,8). Nevertheless, adequate maintenance is essential to achieve consistent effluent quality. As such, a CCP facilitator may end up improving the maintenance program to ensure that improved performance achieved during a CCP is maintained.

The first step in addressing maintenance factors is to document any undesirable results of the current maintenance effort. If plant performance is degraded as a result of maintenance-related equipment breakdowns, the problem is easily documented. Likewise, if extensive emergency maintenance events are experienced, a need for improved preventive maintenance is easily recognized. Ideally, these factors should have been previously identified and prioritized during a CPE. However, most POTWs do not have such obvious evidence directly correlating poor maintenance practices with poor performance. For these POTWs, maintenance factors would not have been identified as limiting performance.

Simply formalizing recordkeeping will generally improve maintenance practices to an acceptable level in many POTWs, particularly smaller ones. A suggested four-step procedure for developing a maintenance recordkeeping system is to: 1) list all equipment; 2) gather manufacturers' literature on all equipment; 3) complete equipment information summary sheets for all equipment; and 4) develop time-based preventive maintenance schedules. Equipment lists can be developed by touring the POTW. As new equipment is purchased it can be added to the list. Existing manufacturers' literature should be inventoried to identify missing but needed materials. Maintenance literature can be obtained from the factory (usually a source is identified on the equipment name plate) or from local equipment representatives. An equipment information sheet is presented in Appendix G. Once sheets are completed for each piece of equipment, a time-based schedule can be developed. This schedule typically includes daily, weekly, monthly, quarterly, semiannual, and annual checkoff lists of required maintenance tasks. An example of this scheduling system is also presented in Appendix G.

The above system for developing a maintenance recordkeeping system has worked successfully at several POTWs. However, there are many other good maintenance references available for use by CCP facilitators and POTW staffs (9-11).

Figure 3-4. Example format for summarizing CCP action items.

DATE: CONCERNS/ACTIONS SUMMARY PAGE NO. 1

No.	Concern	Action Implementation Plan	Assigned To	Date Assigned	Date Due
1	Process Control Spreadsheet	Update daily data on a weekly basis	Larry	3/15	3/22
2	Sump pump for RAS vault	Purchase and install, Coordinate electrical requirements	Bob	2/26	4/2

3.3.5 *Improving Administrative Performance-Limiting Factors*

Administrators who are unfamiliar with plant needs and thus implement policies that conflict with plant performance are a commonly identified factor. For example, such items as implementing minor modifications, purchasing testing equipment, or expanding operator coverage may be recognized by plant operating personnel as needed performance improvement steps but changes cannot be pursued due to lack of support by non-technical administrators. Administrative support and understanding is essential to the successful implementation of a CCP. The following techniques have proven useful in overcoming administrative limitations:

- *Involve plant administrators from the start of the CCP.* The initial site visit should include time with key administrators to explain the CCP process and possibly include a joint plant tour to increase their understanding of plant processes and problems.

- *Focus administrators on their responsibility to produce a "product" that meets regulatory requirements.* Administrators may be reluctant to pursue corrective actions because of lack of understanding of their responsibilities in producing clean water from the plant's treatment processes.

- *Listen carefully to the concerns of administrators* so that they can be addressed during the CCP. Some of their concerns or ideas may be technically unimportant, but are very important "politically." Political influence as well as technical limitations must be addressed and are considered to be an integral part of the activities of a CCP facilitator.

- *Use technical data based on process needs* to convince administrators to take appropriate actions; do not rely on "authority." Alternatives should be presented, when possible, and the administrators left with the decision.

- *Initiate a process control coordination committee.* In larger plants it is often advantageous to establish a process control coordination committee. The purpose of this committee is to meet routinely (weekly) to discuss process control decisions and direction. It should include, as a minimum, one representative each from operations, maintenance, laboratory, and administration. These meetings encourage communication and understanding since each party has a different perspective yet is focused on the common objective of effluent quality.

- *Encourage intimate involvement of plant staff in the budgeting process.* Budget involvement has been effective in motivating plant staff as well as encouraging more effective communication.

- *Include a plant-specific "management audit" as a portion of the CCP.* An example audit that has been used to more effectively describe administrative factors is shown in Appendix H. Results from an audit of this type have been used to effectively encourage improvement of administrative factors that are limiting performance, since the plant staff has an opportunity to provide constructive, confidential feedback on many topics that are often sensitive.

- *Encourage financial planning* for modification and replacement of POTW equipment structures. This type of planning encourages communication between administrators and plant staff through the need to accomplish both short- and long-term planning. Many reference materials are available to assist the CCP facilitator in guiding activities in this area (12,13).

3.3.6 *Improving Operational Performance-Limiting Factors*

Improvement of POTW operations during a CCP is achieved by providing training while improved process control procedures, tailored for the particular plant, are developed and implemented. The initial training efforts should be directed at the key process control decision-makers. In most plants with flows less than 22 L/s (0.5 mgd), one person typically makes and implements all major process control decisions. In these cases, on-the-job training is usually more effective than classroom training and is recommended. If possible in plants of this size, a "back-up" person should also be trained. As the number of operators to be trained increases with plant size, the need for and effectiveness of combining classroom training with on-the-job training also increases.

As discussed in Section 3.2, process control is a key aspect of implementing a CCP because it represents the essential step that enables a capable plant to achieve the ultimate goal of producing a plant effluent in compliance with regulatory requirements. A detailed discussion of process control for suspended growth and fixed film facilities is presented.

3.3.6.1 Suspended Growth Process Control

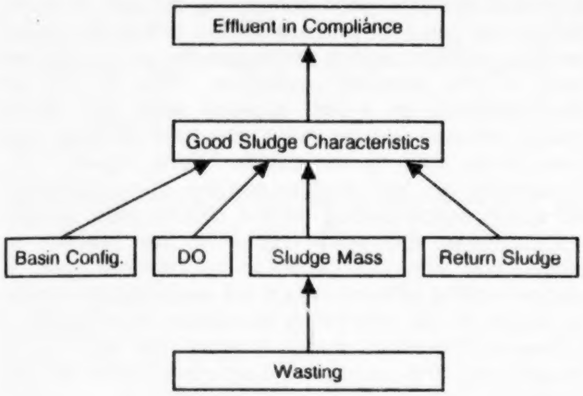
Process control of suspended growth facilities can be achieved through control of the following important parameters associated with the process:

- Activated sludge mass
- Return sludge flow
- Aeration basin DO
- Aeration basin configuration

These items can be utilized to apply "pressure" to the biological environment. If a particular pressure is held for an adequate length of time to get biological system response, a desired change in activated sludge characteristics - such as settling velocity - will result.

The relationships between sludge characteristics, pressure, and time for biological system response relative to process control parameters are graphically depicted in Figure 3-5.

Figure 3-5. Relationship between suspended growth process control parameters and effluent quality.



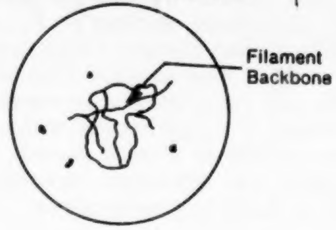
a. Suspended Growth Characteristics
The primary objective of suspended growth process control is achieving good performance by maintaining proper sludge characteristics (e.g., those physical and biological characteristics of a sludge that determine its ability to remove organic material from wastewater). Obtaining good sludge characteristics requires that filamentous and zoogleal bacteria be in proper balance. Enough filaments should be present to form a skeleton for the floc particles, but the filaments should not extend significantly beyond the floc.

More filaments tend to produce a slower settling, larger sludge floc that produces a clearer supernatant. Too many filaments, however, produce a sludge that will not adequately settle and thicken in the final clarifier, often causing sludge to be carried over the clarifier weirs. Having fewer filaments produces a more rapid settling sludge but also leaves more turbidity. The faster settling, small sludge floc exhibits discrete settling and produces "pin floc" or "straggler floc" as well as higher turbidities. A representation of a microscopic view of this desirable type of sludge is shown in Figure 3-6 (14).

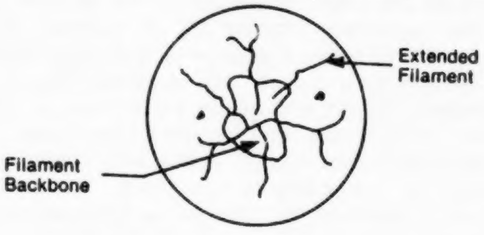
It is desirable to obtain good solids/liquid separation and the good sludge thickening characteristics of a faster settling sludge along with the high quality effluent produced by a slower settling sludge. This is achieved by process control to obtain the best balance of fast- and slow-settling characteristics. Settling tests and microscopic examinations can be used to monitor the sludge conditions shown in Figure 3-6.

Figure 3-6. Representations of activated sludge floc.

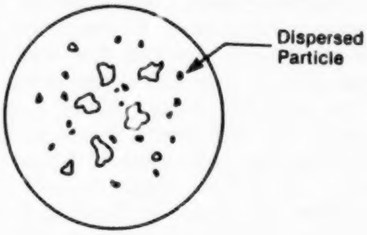
Desirable Activated Sludge Floc



Undesirable Slow-Settling Activated Sludge Floc



Undesirable Fast-Settling Activated Sludge Floc



b. Suspended Growth Mass Control
Suspended growth mass is controlled to achieve and maintain desired sludge characteristics and, as such, represents a critical aspect of good process control. There are several ways to control sludge mass in a POTW. These variations put emphasis on different calculations or different control parameters, but the basic objective of each is to obtain the desired mass of desirable microorganisms in the system.

A common mass control technique is based on maintaining a relatively constant MLSS concentration. Another technique attempts to adjust sludge mass to produce a desired food to microorganism ratio (F/M). Yet another attempts to maintain a consistent average age of the activated sludge in the system, (e.g., mean cell residence time [MCRT]).

Mass control schemes based on the mass of sludge in the aeration basin (e.g., MLSS control) assume that variations in the amount of sludge in the secondary clarifiers is insignificant. A preferred approach includes secondary clarifier sludge in the mass control monitoring program.

The F/M method of sludge mass control is difficult to implement because a method to quickly and accurately monitor the food portion of this parameter is not commonly available. Typically, BOD_5 or chemical oxygen demand (COD) are used to indicate the amount of food available. The BOD_5 test requires five days to complete and is therefore unsatisfactory for process control purposes. Although the COD test can be completed in only several hours, it requires equipment and laboratory capabilities that are not usually available in smaller plants.

Mass control using the MCRT approach can be set up to include the mass of sludge in the aeration basin and the secondary clarifier (6). A variation of this technique is to select a desired level of total mass for the system (e.g., both the aeration basin and secondary clarifier) and adjust the amount of sludge wasted to approach the selected total mass. It is recommended that one of these two strategies be selected for controlling sludge mass. The following discussion identifies the differences between the two strategies.

Suspended growth mass control using the MCRT approach requires that the total sludge mass be measured each day and that total be divided by the target MCRT. This calculated mass is then attempted to be wasted. Actual MCRTs are calculated by dividing the total sludge mass in the system by the actual sludge mass wasted. Actual data for a 3-week period of sludge mass control using the MCRT approach are shown in Figure 3-7. During this period the target MCRT was kept constant at 10 days. The data in Figure 3-7 show that fairly constant MCRT can be maintained. From a process control viewpoint, an advantage of mass control by this method is that it requires daily wasting.

Sludge mass control using the total mass in the system approach requires that wasting be varied depending on increases or decreases in the total sludge mass. For example, if the total sludge mass was increasing above the selected target level, wasting would be increased until the desired sludge mass was again achieved. Actual data for a 3-week period of sludge mass control using the target total mass approach are shown in Figure 3-8. An important observation from Figure 3-8 is that total mass was held relatively constant despite individual MCRTs ranging from 10 to infinity (no wasting that day). Control of total sludge mass can be a useful process control parameter, especially in activated sludge plants where wasting cannot be completed every day.

c. Return Sludge Flow Rate Control

The distribution of sludge between the aeration basin and secondary clarifier can be controlled by adjusting the return sludge flow rate. In general, return sludge flow rate control should be used to maximize the sludge mass and sludge detention time in the aeration basin and minimize the sludge mass and sludge detention time in the final clarifier. This represents the optimum condition for an aerobic biological treatment system and can be summarized as maximizing the sludge distribution ratio (aerator sludge mass divided by clarifier sludge mass).

A general misconception concerning the use of return sludge flow rates for process control is that increasing the flow of return sludge decreases the sludge blanket level in the secondary clarifier. This is not as straightforward as it first appears since the return sludge ultimately contributes to the total hydraulic and total solids load to the clarifier (see Figure 3-9). Depending on the sludge settling characteristics, increased solids loading on the clarifier may or may not increase the solids mass in the clarifier in conjunction with the faster solids removal rate. If sludge settling characteristics are such that the mass of sludge in the clarifier is increased as a result of increasing the return sludge flowrate, the objective of maximizing the sludge distribution ratio is not achieved.

Two levels of improved sludge return control are typically encountered when implementing a CCP: gross adjustments to achieve normal operating ranges followed by fine tuning to further optimize the sludge distribution ratio. Thus, a grossly out-of-line return rate should first be adjusted to at least fall within the appropriate range presented in Table 2-5. Most suspended growth plants with design flows of less than 88 L/s (2 mgd) are designed conservatively enough (e.g., Type 1 plants) that gross adjustments to bring the return sludge flow rate within normal ranges often provide sufficiently improved control. The applicability and results of gross sludge return adjustments are illustrated by the following example:

> An activated sludge plant was experiencing almost continuous problems with solids loss in the final clarifier effluent. This continued despite repeated efforts by the plant superintendent to control the filamentous nature of the sludge. The superintendent had tried chlorinating the aeration basin contents and had even dumped the entire contents of the aeration basin to polishing ponds. Review of plant operation records indicated that the return sludge flow rates were about 150 percent of the raw wastewater flow rate. After a discussion of the advantages of a lower return rate, the superintendent reduced the return sludge rate to about 50 percent of the raw wastewater flow. Solids loss from the clarifiers stopped in about 3 hours.
>
> This gross return rate adjustment did not solve the filamentous sludge problem, but it did significantly improve plant performance. At the higher return rate, hydraulic loading to the final clarifier had been 2.5 times the raw wastewater flow. After the adjustment, the hydraulic loading was reduced to

Figure 3-7. **Activated sludge mass control using MCRT.**

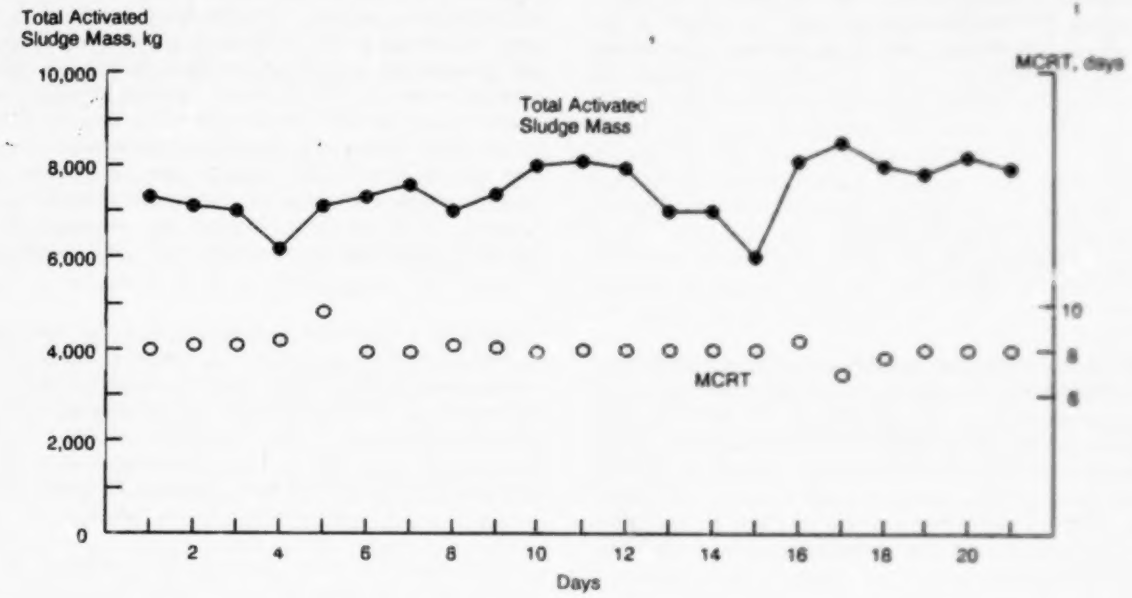


Figure 3-8. **Activated sludge mass control using total sludge mass.**

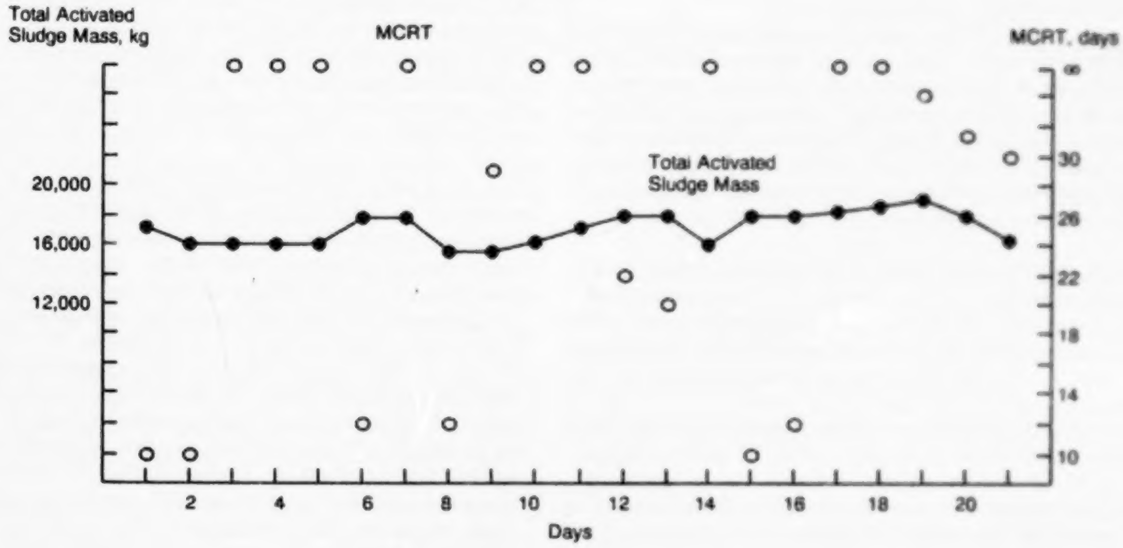
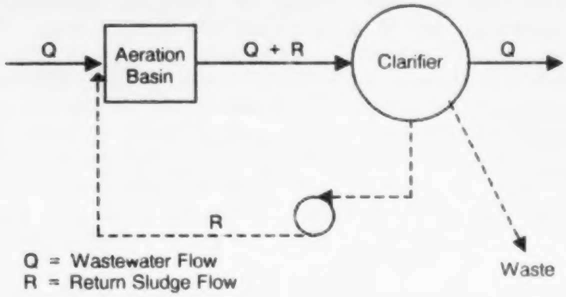


Figure 3-9. Simplified activated sludge process diagram.



> 1.5 times the raw wastewater flow. Although clarifier surface overflow rates were not affected, detention time in the clarifier for settling was increased by 67 percent and solids loading to the clarifier was reduced by 40 percent. These changes greatly enhanced the solids/liquid separation capabilities of the clarifier to be more compatible with the existing sludge settling characteristics.

Plants where gross return sludge flow adjustments do not produce the desired results require a higher level of return sludge flow control. Return sludge flow adjustments need to be compatible with changes such as diurnal variations in wastewater flow and/or variations in sludge settling characteristics that occur due to diurnal variations in POTW loadings. The selection of a specific fine-tuning technique, and evaluation of the results, is best left to the skill and judgment of an experienced CCP facilitator and is not discussed in this document.

d. Aeration Basin DO Control

Oxygen levels in an aeration basin can be used to promote or hinder the growth rates of filamentous organisms in suspended growth processes (5,6,14,15). DO control can therefore be used to promote the desired balance between filamentous and zoogleal microorganisms, which controls sludge settling characteristics and ultimately leads to improved plant performance.

In activated sludge plants, the greatest single use of energy is for aeration and mixing in the aeration basin. The desire to cut energy and associated costs while maintaining good performance makes the decision as to how much oxygen to use a critical one. Some guidelines and tests that have been used to aid in making this decision in other plants are discussed below.

Oxygen supply in an aeration basin can be thought of as satisfying two needs: oxygen demand and residual DO. Typically, these are satisfied without differentiation, but an understanding of both may be helpful when developing a DO process control approach. Oxygen demand is the mass of oxygen required to meet BOD$_5$ and nitrification demands and to maintain a viable microorganism population. The required residual DO is that mass of oxygen needed to provide the environment that produces desired sludge settling characteristics. The residual DO, which exists in an aeration basin when the oxygen demand is satisfied, varies with the type of process. Generally, the higher the BOD$_5$ loading rate on the activated sludge system, the higher the aeration basin oxygen uptake rates and the higher the residual DO. A general guideline for residual bulk DO is shown in Figure 2-2.

Operating experience has shown that DO becomes a growth-limiting factor for zoogleal-type microorganisms before becoming a limiting factor for filamentous microorganisms. DO control at low levels in an aeration basin can therefore be used to apply "pressure" to shift sludge characteristics toward slower settling. Conversely, higher DO levels can be used to apply "pressure" for faster settling.

If a decision is made to lower DO, proper testing is essential to ensure that adequate oxygen is being transferred. Tests that will be most beneficial are residual DO measurements and oxygen uptake rate tests (16). Residual DO measurements should be taken initially at several locations throughout the aeration basin and verified periodically to determine a sample point that can be considered "average." When determining residual DO, it is important to take measurements several times during the day to be coincident with diurnal BOD$_5$ loading variations. In general, plants operating at low DO levels during peak loading may still provide good treatment if considerably higher DO residuals exist before the day's peak loading is received. For example, a plant may operate very successfully with a DO of 0.4-0.6 mg/L during the day if the morning DO is 1.0-1.5 mg/L. This daily fluctuation in DO levels can produce the desired mix of zoogleal and filamentous organisms.

The oxygen uptake test can also be used as a measure of adequacy of oxygen transfer (17). If the oxygen uptake test indicates an oxygen demand significantly greater than 0.65 kg O$_2$/kg BOD$_5$ removed plus 0.1 kg O$_2$/kg total sludge in an activated sludge system, the test may be indicative of an inadequate oxygen supply. For example, an activated sludge facility was removing approximately 240 kg (530 lb) BOD$_5$/d with a total sludge mass in the aeration basin and secondary clarifier of about 2,000 kg (4,500 lb). The calculated oxygen demand is [(240 kg BOD$_5$/d) x (0.65 kg O$_2$/kg BOD$_5$)] + [(2,000 kg sludge) x (0.1 kg O$_2$/kg sludge/d)], or 356 kg (783 lb) O$_2$/d. However, the measured oxygen uptake in the 760-m^3 (200,000-gal] aeration basin was 30 mg/L/hr, or 550 kg (1,200 lb) O$_2$/d (150 percent of the calculated oxygen demand). These results indicated that the realistic oxygen requirements are not being met with the current residual DO of 0.5-0.8 mg/L. Oxygen supply was increased, turbidity of the effluent dropped, and the oxygen demand measured by the oxygen uptake rate decreased to 110 percent of the calculated demand.

The above illustrates the use of a successful troubleshooting technique for identifying and correcting a DO deficiency. Like return sludge control, the capability to use DO control to fine tune activated sludge processes is a function of the experience and technical judgment of the CCP facilitator.

e. Aeration Basin Configuration

Sludge characteristics and thus plant performance can often be improved by utilizing different aeration basin loading configurations. For example, the adverse impacts of extremes in flow and BOD_5 loading variations can be minimized by operating in the step feed or contact stabilization mode as opposed to plug flow. For a more detailed discussion of utilizing aeration basin configurations to improve process performance, see Section 4.4.2.

f. Process Control Pressure

As discussed in Section 3.3.6.1a, overall suspended growth process performance is primarily a function of the sludge characteristics. Process control tests and adjustments should be made with the purpose of achieving desired sludge characteristics. The specific process controls discussed earlier (sludge mass, sludge returns, aeration basin loading configuration, and aeration basin DO) are used to apply "pressure" to develop desired sludge characteristics by changing the environment for the sludge mass. A combination of operational adjustments may be necessary to provide enough pressure to achieve the desired changes. For example, if sludge settling had slowed to an undesirable level and a wet weather season (which will cause higher average and peak clarifier hydraulic loadings) was approaching, it would be advantageous to expedite efforts to increase the settling rate. Simultaneous adjustments of several process control parameters could be used to provide more pressure in the desired direction. In general, a raise in aeration basin DO, more frequent return rate adjustments to minimize sludge mass and sludge detention time in the clarifier, and converting to a step loading mode would all be appropriate to achieve faster settling.

g. Time for Biological System Response

When making process control adjustments at suspended growth facilities, it is important to realize that, although some changes take place quite rapidly, some changes in sludge characteristics develop slowly and adequate time must be allowed for the biological system to respond to the pressures applied. Adjustments change the environment of the activated sludge very quickly, but a considerably longer period of time may be required before sludge characteristics change to reflect the new environment. For example, if low DO in a diffused air aeration basin is believed to be a cause of slow-settling sludge, it would be appropriate to increase the oxygen transfer by increasing blower output. Two changes should be monitored, one immediate and one long-term. Mixed liquor DO measurements a few hours after the change as well as the next day should indicate whether the increased blower output selected was sufficient to change the environment (DO level) in the aeration basin, but it may take several weeks of sludge settling tests to determine if that new environment applied enough pressure to cause the sludge to settle more rapidly.

A tendency to return to status quo if a desired result is not achieved quickly has been observed at many plants. In the above example, a person using a trial and error approach may decide after 3 days of higher DO concentration in the aeration basin that additional aeration was the wrong adjustment and a waste of energy. However, a person directing a CCP must have enough experience and confidence to hold the changed environmental conditions long enough to produce the desired result. If the desired change in sludge characteristics has not started to take place in a length of time equal to two or three MCRTs, additional pressure should be applied. As a general reference, a time equal to three to five MCRTs is necessary to establish changes in sludge characteristics.

An acceptance of the time required for a biological system to respond to new process control adjustments should be a major training objective of the CCP effort. Graphing process monitoring results to produce trend charts can enhance this acceptance.

h. Suspended Growth Testing

Several references are available for selecting tests and their frequency for suspended growth plants (15,18,19). Appendix I contains an example process control daily data sheet that has proven useful in monitoring activated sludge POTWs. To achieve adequate process control, all activated sludge plants should include monitoring for at least the following:

- Sludge settling
- Total sludge mass control
- Sludge wasting
- Return sludge concentration and flow control
- Aeration basin DO control

Figure 3-3 illustrates a process control test recording sheet for an 11-L/s (0.25-mgd) extended aeration package plant. Process control tests for this plant were conducted once per day, 2 days per week. Larger activated sludge POTWs require that similar parameters be monitored. However, since larger plants are often designed less conservatively, they require more frequent monitoring and more frequent process adjustments. For example, at a 241-L/s (5.5 - mgd) activated sludge plant, settling and mass control tests were conducted once per 8-hour shift, 7 days per week.

As a further example, Table 3-3 illustrates a testing schedule for a 2-L/s (50,000-gpd) plant that is subjected to highly variable conditions due to drastic climate changes and wide seasonal population fluctuations. The concept of providing two different frequency schedules is a compromise between the desirable higher frequencies and the minimum operator time typically allocated to this function in small facilities. Under normal operating conditions with little stress on the processes, the "routine" frequency is adequate. When the system is under stress (e.g., peak seasonal populations), the "critical" frequency is appropriate.

Table 3-3. Process Control Monitoring at a Small Activated Sludge Plant

Test, Parameter, or Evaluation	Frequency Routine	 Critical*
Activated Sludge:		
Control Tests	3/week	Daily
Centrifuge Spins (Aeration Tank Conc./ Return Sludge Conc./Clarifier Core Sample Conc.), Settleometer Test, Depth to Blanket, Aeration Basin DO		
Control Calculations	3/week	Daily
Total Sludge Mass, Aerator Sludge Mass, Clarifier Sludge Mass, Return Sludge Percentage, Sludge Distribution Ratio, Clarifier Solids Loading, MCRT		
Control Plots	3/week	Daily
Graph 1: Settling Results, Return Sludge Conc., Aerator Conc. Graph 2: Total Sludge Mass (Aerator and Clarifier), Wasted Sludge Mass		
Wasting		
Volume, Concentration, Mass	3/week	Daily
Digester:		
DO, Concentration, Temperature, pH	Weekly	2/week
Waste Activated Sludge, Digested Sludge, Volatile Solids Percentage, Volatile Solids Reduction	Monthly	2/month
Chlorine Residual:	5/week	Daily

* "Critical" refers to periods of transition to higher loadings and during peak loadings and periods of stressed operation, i.e., bulky sludge, process out of service, or major change in process control.

3.3.6.2 Fixed Film Process Control

Fixed film (trickling filter and RBC) POTWs are not impacted to the same degree by process adjustments as are suspended growth facilities (7,8) since there are only a limited number of process adjustments that can be optimized. The potential improvement in effluent quality due to improved process control is accordingly less. Areas of process control that can be optimized to improve fixed film facility performance are discussed below.

a. Reducing Return Process Stream Loadings
The CCP facilitator should strive to reduce the BOD_5 loading returned through the plant from anaerobic digestion and from sludge dewatering operations. Disposal of all digester supernatant with the digested sludge can significantly reduce plant BOD_5 loadings. This practice has been implemented most frequently in smaller POTWs where sludge disposal is by liquid haul to nearby farmland. Another way to achieve partial BOD_5 load reduction is by "filtering" the digester supernatant through a drying bed.

When dewatering digester sludge with a belt press, vacuum filter, or centrifuge, chemical dosages are often minimized to lower costs. If a low solids capture is being accomplished, increased chemical usage to increase capture and reduce the impact of return flow on the plant should be considered. A more detailed description of alternatives for reducing sidestream loading is included in Chapter 4.

b. Optimizing Clarifier Operation
Process control adjustments can be used to optimize primary clarifier performance (e.g., decrease BOD_5 loading on subsequent fixed film processes). Similarly, process control adjustments can be used to optimize secondary clarifier performance. BOD_5 and TSS removals in both primary and secondary clarifiers can be typically improved by minimizing surface overflow rates and controlling sludge quantities in the clarifiers.

Surface overflow rates can be minimized by eliminating any unnecessary flow through the clarifiers. A common situation occurs when trickling filter recycle is directed through either the primary or secondary clarifier. In this case, a facility modification to provide recirculation only through the fixed film process is typically justified.

Keeping sludge blanket levels and sludge detention times low in both primary and secondary clarifiers typically enhances BOD_5 and TSS removals. These operational objectives can often be accomplished by increasing sludge pumping. Care must be exercised to ensure that removed sludge is not so thin that it adversely affects sludge treatment processes. Experience and judgment of the CCP facilitator must be used to achieve the best compromise.

c. Media Cleaning/Flushing
Solids accumulation in fixed film facilities can decrease BOD_5 removal efficiency and result in uncontrolled sloughing events that can overload secondary clarifiers. Various process control procedures can be used to regulate these occurrences.

Varying the recycle rate, and thus the hydraulic application rate, can promote sloughing. Additionally, increased recycle can help distribute the BOD_5 load throughout the filter depth. At plants having multiple filters, all of the wastewater flow can be directed to one filter on a periodic basis (e.g., weekly). Another practice, called "walking the filter," hydraulically overloads a section of the filter by physically restraining the rotational speed of the distributor arm. One method of accomplishing this procedure involves the plant operator tying a rope or cable to the arm and slowly "walking" the arm around the filter on a periodic basis.

In addition to increasing the hydraulic loading, "flooding" of fixed film filters has been used to aid in controlling solids accumulation. Also, if the media is in good condition, it can be removed and cleaned and then placed back in service (21).

d. Fixed Film Testing

Process control monitoring for fixed film facilities is generally less extensive than for suspended growth systems. The performance of the primary clarifier, fixed film reactor, and final clarifier should be monitored on a routine basis. Fixed film reactor performance can best be monitored by measuring soluble BOD_5 removals since this test directly measures the unit's capability to convert dissolved and colloidal organics to microbial solids. An example process control summary sheet developed for a 88-L/s (2-mgd) RBC POTW is presented in Appendix J.

3.3.6.3 ABF Process Control

The ABF process contains elements of both suspended growth and fixed film facilities. Sludge characteristics (settling rates, compaction capability, appearance, etc.) are more like that of fixed film sludge in that wide fluctuations are not common. Consequently, overall sludge return rates and diurnal adjustments are not as critical for the ABF process as they are for activated sludge processes. The same is true for aeration basin DO. DO must be provided to meet the demand in an ABF system without special consideration for the residual DO and its effect on sludge settling characteristics (20). A DO residual of 2-3 mg/L is usually sufficient.

The process control parameter in an ABF system that is similar to an activated sludge system and slightly more susceptible to problems is suspended growth sludge mass control. Mass control is critical in an ABF system because a large fraction of the mass, usually one-quarter to one-half, is wasted daily. Process control parameters monitored in two ABF POTWs are presented in Appendix K.

3.4 Example CCP

An example CCP is difficult to present because many of the performance-limiting factors are addressed through training, interpersonnel relationships, weekly data review, phone consultations, and other activities conducted over a long period of time. These activities do not lend themselves readily to an abbreviated discussion (3). Despite these limitations, an overview of a CCP is presented based on the example CPE presented in Section 2.3.8.

3.4.1 Addressing Performance-Limiting Factors

The most serious performance-limiting factors identified in the CPE were process control oriented. The major emphasis, therefore, of the initial portion of the CCP was directed at improving plant operations (process control).

1. Operation (Process Control)

- A process control testing schedule to monitor sludge settling, sludge mass, sludge wasting, sludge return concentration and flow, and aeration basin DO was established using the guidelines in Table 3-3. On-the-job training was provided in the areas of specific process control sampling and testing requirements (see Section 3.3.6).
- A process control summary sheet was developed and process control calculations were implemented as shown in Appendix I.
- Trend graphs were initiated to monitor activated sludge mass inventory and wasting, and activated sludge settling characteristics and return sludge concentrations.
- Sludge wasting requirements were documented to provide justification for adequate sludge disposal capability.

Results of the improved process control activities led to the following sequence of events:

- Operational tests showed that actual sludge production averaged 0.81 kg TSS produced/kg BOD_5 removed. This actual value was higher than the projected sludge production of 0.65 kg TSS/kg BOD_5 removed used for evaluation in the CPE, further aggravating the capacity limitation of the anaerobic digester.
- POTW administrators were presented with the sludge production results by using the following explanation: "Your POTW treats about 350 million gallons of wastewater a year which results in about 5.5 million gallons of sludge. This sludge must be disposed of properly. The existing aerobic digester is too small to handle the total sludge produced. This one deficiency negates a significant portion of the pollution control already accomplished in the rest of the plant. If you want to bring your plant into compliance and obtain full benefit from the rest of the plant, additional acceptable sludge handling capacity will have to be provided."

- After considering various options, including construction, it was decided to utilize a contract hauler to dispose of liquid sludge in a nearby large POTW at a charge of $0.22/L ($0.06/gal).
- The first month of contract hauling resulted in a supplemental sludge disposal cost of $4,500 and all involved believed a significant effort to reduce this cost was justified. An effort was made to increase the concentration of the sludge fed to the digester by thickening the sludge in an old clarifier available on the plant site. Polymer was used to aid in the sludge thickening. After several trial tests, a polymer was found that significantly improved waste sludge concentrations from the "thickening tank." The concentration fed to the digester was increased about 250 percent by adding 20-25 lb polymer/ton sludge solids. The net effect was to decrease supplemental sludge disposal cost by 56 percent from the $4,500/month initially incurred.

2. Design

- Minor piping changes and a polymer feed system had to be provided to use the available tankage at the plant as a "thickener." Major facility modifications, such as enlarging the aerobic digester, were avoided.

3. Maintenance

- Suggested preventive maintenance forms (similar to those in Appendix G) were provided the plant superintendent. However, lack of a documented preventive maintenance program had not been a significant performance-limiting problem and consequently, no additional emphasis was placed on plant maintenance.

4. Administration

- Administrators' familiarity with plant needs and their ability to make appropriate decisions regarding the plant was increased by describing process requirements, providing oral status reports, and involving them in correction of the sludge capacity deficiency.

3.4.2 Plant Performance

Plant performance was improved dramatically by implementation of the CCP. The results are summarized below:

	Effluent BOD_5, mg/L	Effluent TSS, mg/L
Before CCP		
Reported	14	15
Estimated Actual	44	75
After CCP		
Actual	14	17

The reported values prior to the CCP were collected only during periods when the clarifiers were not losing solids. The estimated actual effluent quality was projected by comparing sludge wasted prior to the CCP with sludge wasted after the CCP was initiated. The difference in these values was projected to have been consistently lost in the plant effluent. Actual results are based on proper testing and represent a true picture of plant performance.

3.4.3 CCP Costs

The costs for the example CPE and CCP described in Sections 2.3.8 and 3.4 are summarized below:

Item	$
CPE Consultant	3,500 (one-time)
CCP Consultant	12,000 (one-time)
Test Equipment	700 (one-time)
Polymer Addition Equipment	550 (one-time)
Sludge Disposal	26,500 (annual)
Polymer	2,500 (annual)
Total	45,750 (first year) 29,000 (ongoing annual costs)

3.4.4 Summary

This example illustrates several important points of the CCP approach and includes several problems and associated solutions that occur frequently during CCP implementation. These are:

- The primary objective of a CCP is attaining adequate performance. A secondary objective can be minimizing costs within the framework of adequate treatment.
- Some potential performance-limiting factors identified during a CPE are later found to be incorrect or less significant when actually eliminating problems with a CCP. This was true of the digester design limitations in this plant.
- The degree of administrative support is sometimes difficult to assess during a CPE but often becomes a major concern during a CCP. This was true when the administrators were faced with supporting dramatically increased sludge handling costs in the example CCP.
- A Type 2 POTW was brought into compliance without major plant modifications.

3.5 CCP Results

The success of conducting CCP activities can be measured by a variety of parameters, such as improved operator capability, cost savings, improved maintenance, etc. However, the true success of a CCP should be documented improved performance to the degree that the plant has achieved compliance. Given this measure, the results of a successful CCP effort can be easily depicted in graphical form. Results from an actual CCP are presented in Figure 3-10. It is desirable to present CCP results in this format.

3.6 Personnel Capabilities for Conducting CCPs

Persons responsible for conducting a CCP must have a comprehensive understanding of wastewater treatment (see Section 2.4), extensive hands-on experience in biological wastewater treatment operations, and strong capabilities in personnel motivation. Comprehensive understanding of, and experience in, biological wastewater processes are necessary because the current state-of-the-art in biological treatment leaves room for individual judgment in both design and process control. For example, references can be found to support the use of a variety of activated sludge process control strategies. Those responsible for implementing a CCP must have sufficient process experience to determine appropriate application of a strategy to the personnel capabilities of the POTW in question. Leadership and motivational skills are required to fill the multi-faceted "facilitator" role required of individuals responsible for implementing a CCP.

Individuals who routinely work in the area of improving wastewater treatment plant performance likely will be best qualified to be CCP facilitators. These persons are, typically, engineers or operators who have focused their careers on wastewater treatment plant troubleshooting and have gained experience in correcting deficiencies at several plants of various types. It is important that CCP facilitators have experience in a variety of plants because the ability to recognize true causes of limited performance is a skill developed only through experience. Similarly, the successful implemen-tation of a cost-effective CCP is greatly enhanced by experience.

By the very nature of the CCP approach, the CCP facilitator must often address improved operation, maintenance, and minor design modifications with personnel already responsible for these wastewater treatment functions. A "worst case situation" is one in which the POTW staff is trying to prove that "the facilitator can't make it work either." The CCP facilitator must be able to deal with this personal issue in such a manner that allows all parties involved to focus on the common goal of achieving desired plant performance.

A CCP facilitator must be able to conduct training in both formal classroom and on-the-job situations. Training capabilities must also be broadly based (i.e., effective with both the operating as well as the administrative personnel). When addressing process control limitations, training must be geared to the specific process control decision-makers. Some may be inexperienced and uncertified; others may have considerable experience and credentials. Administrative "training" is often a matter of clearly providing information to justify or support CCP activities. Although many administrators are competent, successful, and experienced, some may not know what their facilities require in terms of manpower, minor modifications, or specific funding needs.

CCP facilitators can be either consultants, including state and federal personnel, or utility employees. When local administrators decide to use a consultant to implement the CCP, they should conduct interviews and check references thoroughly. A substantial construction cost could be incurred if an inexperienced facilitator is not capable of bringing a capable POTW to the desired level of treatment. Another important attribute of a consultant providing CCP services is the ability to explain problems and potential solutions clearly in a non-threatening manner.

When local administrators decide to conduct a CCP without the services of outside personnel, they should recognize that some inherent problems may exist. The individuals implementing the CCP, for example, often find it difficult to provide an unbiased assessment of the area in which they normally work: operating personnel tend to look at design and administration as problem areas; administrators typically feel the operating personnel should be able to do better with what they have; the engineer who designed a facility is often reluctant to admit design limitations, etc. These biases should be recognized and discussed before personnel closely associated with the POTW initiate a CCP.

3.7 Estimating CCP Costs

CCP costs vary widely depending on: 1) the size and complexity of the facility; 2) who implements the CCP; 3) the number and nature of performance-limiting factors; and 4) the capability and cooperation available from the POTW technical and administrative staff. The cost of a CCP falls into two main areas: 1) cost of a consultant to implement the CCP; and 2) cost of implementing activities to support the CCP effort, such as minor plant modifications, additional staffing, more testing equipment, and certain process changes. Estimated costs for using a CCP consultant are presented in Table 3-4.

Wide ranges are presented in Table 3-4 because the performance-limiting factors generally vary widely from plant to plant and require different types and amounts of training before they can be eliminated.

The costs of implementing activities to support the CCP effort and for operating the POTW at a higher level of performance are difficult to generalize. They must be developed on an individual POTW basis

Figure 3-10. Graphical presentation of improved performance from a successful CCP.

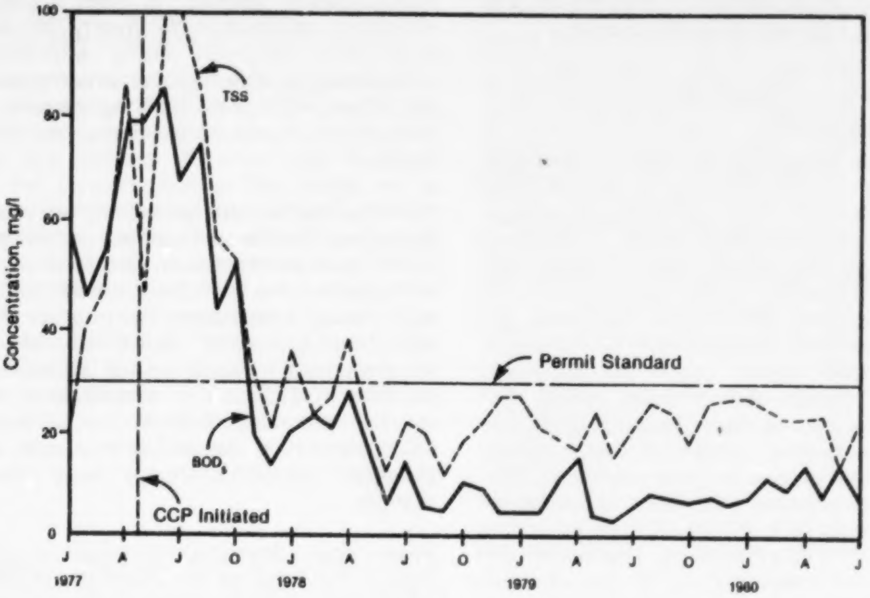


Table 3-4. Typical Costs for Conducting a CCP[a]

Type and Size of Facility	CCP Consultant Cost (1988 $)
Suspended Growth:[b]	
<9 L/s (0.2 mgd)	3,000-20,000
9-88 L/s (0.2-2 mgd)	5,000-50,000
88-440 L/s (2-10 mgd)	15,000-100,000
Fixed Film:[c]	
<22 L/s (0.5 mgd)	3,000-25,000
22-440 L/s (0.5-10 mgd)	5,000-80,000

[a] For contract consultant.

[b] Includes all variations of activated sludge, and ABF systems.

[c] Includes trickling filters with both plastic and rock media and RBCs.

since they are more dependent on the particular performance-limiting factors than the size or type of facility. In most CCPs these costs equal or exceed the typical costs of a CCP consultant, as presented in Table 3-4.

3.8 References

When an NTIS number is cited in a reference, that reference is available from:

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
(703) 487-4650

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Chapter 4
Facility Modifications

4.1 Introduction

If a POTW is having difficulty in complying with its permit requirements, a formalized problem identification and correction procedure will ensure a cost effective approach for achieving facility compliance. Figure 4-1 presents such an approach. The first step taken should be a thorough evaluation of all factors that may be limiting performance at the POTW. Such an evaluation, called a Comprehensive Performance Evaluation (CPE), is described in Chapter 2. A portion of the CPE includes an evaluation of major unit processes that results in the plant being categorized as Type 1, 2, or 3. If it is determined that performance cannot be expected to improve significantly until facility modifications are constructed, the plant is categorized as Type 3. Compliance is possible with Type 1 and 2 plants through optimization of existing facilities. A facility optimization approach, called a Composite Correction Program (CCP), is described in Chapter 3. Often during the conduct of the CCP, design limitations are identified. Facility modifications are also required to achieve compliance at these plants.

This chapter describes various modifications that can be utilized at an existing POTW to eliminate identified design limitations. This manual is not intended to replace a detailed engineering study that may be necessary to evaluate factors beyond the scope of this manual such as site constraints, pressure for growth, and more stringent effluent requirements. These conditions may warrant the replacement of existing facilities with new facilities.

4.1.1 Identifying Alternatives

Facility modifications that result in improved compliance with effluent BOD_5, TSS, and coliform permit requirements (i.e., secondary treatment standards) are the emphasis of this chapter. Compliance-limiting unit processes are most often the secondary treatment units (i.e., the "aerator" and the secondary clarifier) and, therefore, modifications to these unit processes are presented in detail. In some instances, the poor performance of a secondary unit process may be due to inadequacies in other unit processes. An example would be an undersized sludge treatment process that restricts sludge wasting such that effluent TSS violations occur. For cases where preliminary, primary, or sludge treatment unit processes contribute to non-compliance, facility modification alternatives are presented.

Once design limitations have been identified, it is possible to begin the process of selecting facility modification alternatives for implementation. The indexed guide presented in Table 4-1 was developed to assist the reader in this selection. Column 1 lists various treatment components grouped by unit processes to assist the reader in identifying those components applicable to their treatment facility. Design limitations that have the potential of limiting overall facility compliance are shown in column 2. Column 3 briefly describes how compliance is typically affected by the design limitation.

After locating the identified design limitations in Table 4-1, the reader is directed by page number to information on specific modifications. The modification alternatives presented in Sections 4.2 through 4.7 are categorized as follows:

Section 4.2 - Preliminary/Primary Treatment Processes - includes modifications to flow equalization, primary clarification, screening, grit removal, and septage handling.

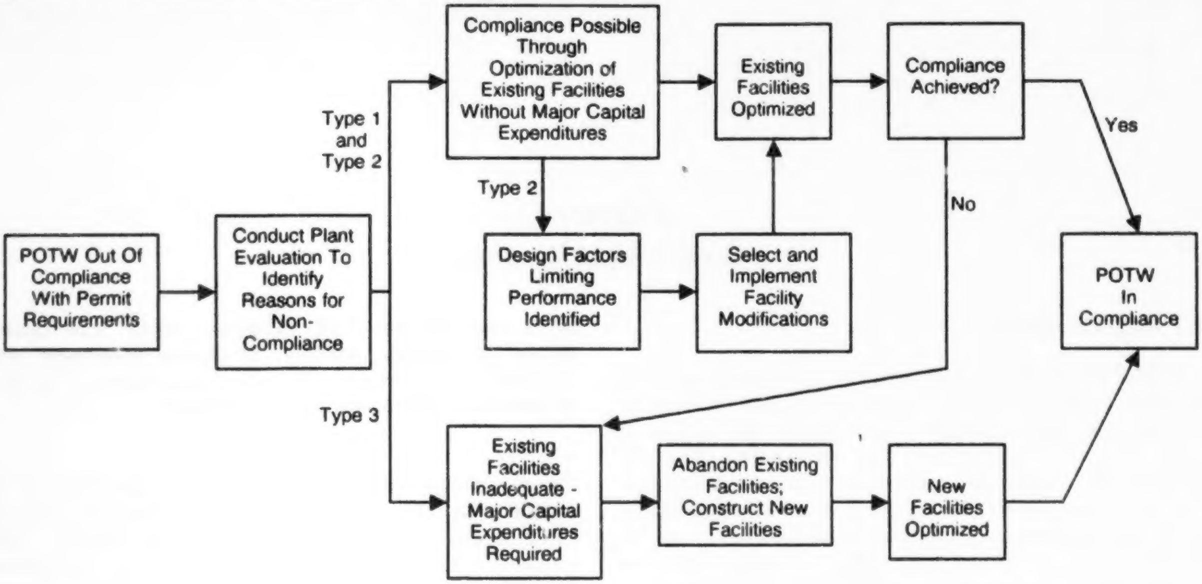
Section 4.3 - Fixed Growth Treatment Processes - includes modifications to trickling filters, rotating biological contactors (RBC), and activated biofilters (ABF).

Section 4.4 - Suspended Growth Treatment Processes - includes modifications to activated sludge systems.

Section 4.5 - Stabilization Ponds - includes modifications to aerobic and facultative stabilization ponds and aerated lagoons.

Section 4.6 - Sludge Treatment and Disposal - includes modifications to sludge thickening, stabilization, dewatering, and disposal processes.

Figure 4-1. Methodology for achieving POTW effluent compliance.


POTW Out Of Compliance With Permit Requirements
Conduct Plant Evaluation To Identify Reasons for Non-Compliance
Type 1 and Type 2
Compliance Possible Through Optimization of Existing Facilities Without Major Capital Expenditures
Type 2
Design Factors Limiting Performance Identified
Select and Implement Facility Modifications
Existing Facilities Optimized
Compliance Achieved?
Yes
No
POTW In Compliance
Type 3
Existing Facilities Inadequate - Major Capital Expenditures Required
Abandon Existing Facilities; Construct New Facilities
New Facilities Optimized

Section 4.7 - Additional Facility Modifications - includes modifications to disinfection systems, analytical and process instrumentation, and emergency systems.

Each section contains a process description, important process control parameters, and a table that summarizes design limitations and associated modifications. The order in which design limitations are presented in the table is based on their potential for improving performance at the POTW. Where applicable, potential operation- and maintenance-related solutions to the identified design limitations are presented.

Each construction-related modification presented includes general design criteria plus advantages, disadvantages, and a physical description of the modification. Case studies and operational guidelines are included when available. References are included for detailed information concerning the specific modification. Specific product and manufacturer references are not provided but can be obtained through the use of the following as well as similar publications:

- JWPCF Buyers Guide (part 2 of the March issue)
- AWWA Buyers Guide (part 2 of the November issue)
- Pollution Engineering (October issue)
- Pollution Equipment News Buyers Guide (November issue)
- Municipal Index Purchasing Guide (published by American City and County Magazine)

4.1.2 Selecting A Modification

Modifications presented in this manual generally fall into one of the following categories:

- addition of unit processes in series or parallel
- "in-tank" modifications (e.g., baffles, aeration modifications)
- modification of wastewater characteristics (e.g., chemical addition, upgrading pretreatment requirements)
- modification of auxiliary processes (e.g., wasting and recycle pumps, piping and valves)

The final selection of a modification is determined by evaluating several conditions. Figure 4-2 presents a decision-making approach for selecting a modification for existing facilities. The decisions are divided into Level I and Level II categories. Level I decisions are more straightforward and relate to site requirements and cost effectiveness. Level II decisions require increased judgment since they involve consideration for such things as reliability and flexibility. Assistance in making Level II decisions is provided in the following sections.

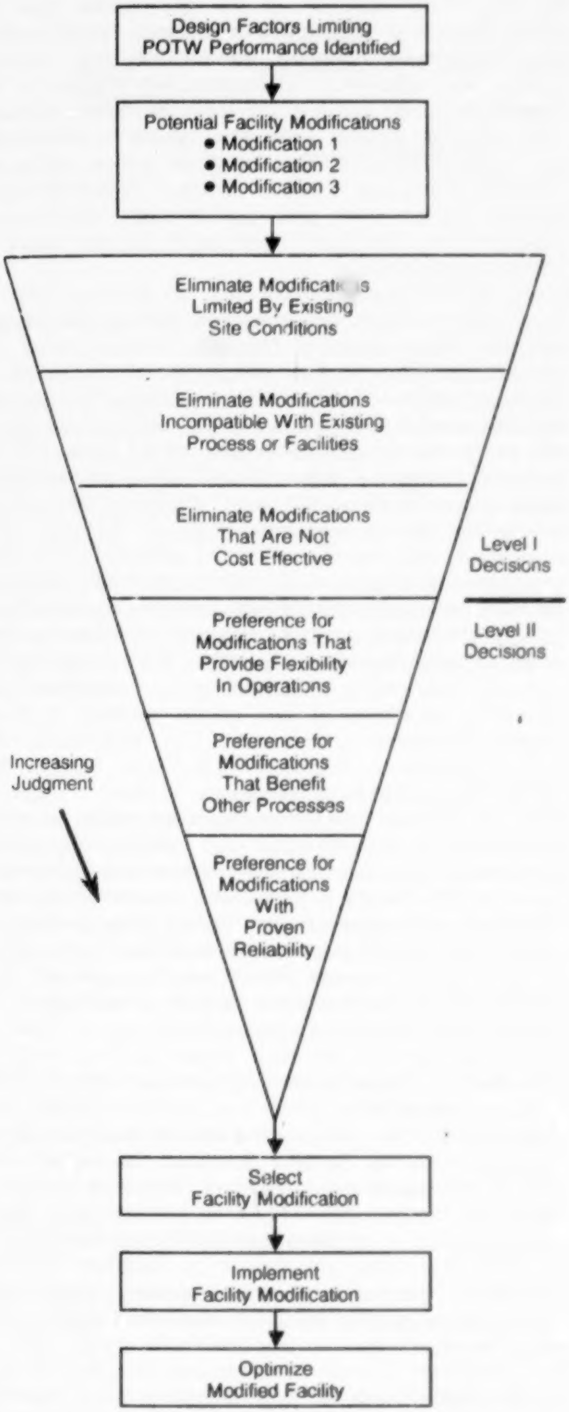
Table 4-1. Summary of Design Limitations

Treatment Component	Page No.	Design Limitation	Associated Performance Problems
4.2 Preliminary/Primary Processes			
Flow Control	67	Excessive flows/load variations	Solids washout from secondary clarifier during peak flow events; hydraulic/organic shocks to biological processes; poor solids removal by primary clarifier
Flow Splitting	70	Inadequate flow splitting and control	Inconsistent treatment efficiency due to excessive flow variations
Screening	70	Inadequate screening efficiency	Damage or plugging of critical equipment
Grit Removal	72	Undersized grit removal process	Fouling of critical equipment; decrease in basin volume due to grit deposition
		Inadequate velocity control	Fouling of critical equipment; decrease in basin volume due to grit deposition
Primary Clarification	72	Undersized basin	Decreased solids removal efficiency causing increased loading to secondary
		Inadequate scum and sludge removal	Decreased solids removal efficiency causing increased loading to secondary
Septage Handling Facilities	73	Undersized or lack of septage handling facilities	Organic toxic shocks to biological processes without primary clarifiers
4.3 Fixed Film Processes			
Trickling Filter	74	Undersized unit process	Organic overload; inadequate SBOD removal, potential odors
		Inadequate oxygen transfer capacity	Inadequate removal of SBOD, odors
		Inadequate hydraulic wetting	Media plugging and inconsistent sloughing Inadequate removel of SBOD
		Lack of cold weather protection	Inadequate removal of SBOD, potential mechanical failure.
RBC	82	Undersized unit process	Organic overload; inadequate removal of SBOD; mechanical problems
		Undersized first stage	Organic overload; inadequate SBOD removal
		Inadequate oxygen transfer capacity	Inadequate removal of SBOD
		Inadequate control of air drive units	Uneven growth; rotational problems; potential mechanical failure
ABF	84	Undersized unit process	Organic overload; inadequate SBOD removal
		Inadequate oxygen transfer	Inadequate removal of SBOD
		Inadequate return/waste sludge capability	Inability to control solids distribution between aerator and clarifier
Clarifier	86	Undersized clarifier	High effluent suspended solids
		Excessive clarifier hydraulic currents	Solids washout; periodic high effluent SS
4.4 Suspended Growth Processes	87	Inadequate waste sludge flexibility/capacity	Inability to control sludge mass in system; periodic high effluent SS and SBOD
		Inadequate process flexibility	Inability to recover from process upsets; solids washout; inability to control sludge characteristics (e.g., bulking); periodic high effluent TSS and BOD
		Undersized clarifier	High effluent SS
		Undersized aeration basin	Organic or hydraulic overload; inadequate removal of SBOD; inability to control sludge characteristics

Table 4-1. Summary of Design Limitations (continued)

Treatment Component	Page No.	Design Limitation	Associated Performance Problems
4.4 Suspended Growth Processes (continued)	87	Inadequate oxygen transfer equipment	Inability to control sludge characteristics; inadequate removal of SBOD
		Inadequate return sludge flexibility	Inability to control solids distribution between aeration basin and clarifier
		Excessive clarifier hydraulic currents	Solids washout; periodic high effluent SS
		Inadequate basin mixing	Short-circuiting; decrease in basin volume due to sludge deposition
		Inadequate scum removal	High effluent SS
4.5 Stabilization Ponds	106	Undersized ponds	Organic overload; inadequate removal of SBOD
		Inadequate oxygen transfer capability	Inadequate removal of SBOD
		Short-circuiting	Inadequate removal of SBOD
		Inadequate suspended solids control	Periodic high effluent SS
		Inflexible mode of operation	Inadequate removal of SBOD; periodic high effluent SS
		Low pond temperature	Inadequate removal of SBOD
4.6 Sludge Treatment and Disposal	115		
Thickening	88	Inadequate capacity and/or flexibility	Periodic inadequate effluent TSS and BOD removal; process upset due to retention of high solids inventory in secondary units
Stabilization	91		
Dewatering	122		
Sidestream Handling	123		
Sludge Storage	123		
Sludge Transportation	124		
Ultimate Disposal	124		
4.7 Miscellaneous			
Disinfection System	124	Short-circuiting	High effluent fecal coliforms
		Inadequate clarifier	High effluent BOD, TSS, and fecal coliforms
		Inadequate feed capacity	Periodic high effluent fecal coliforms
		Undersized basin	Sustained periods with high effluent fecal coliforms
Miscellaneous Systems	129	Inadequate instrumentation	Unreliable effluent SS and/or SBOD due to unavailable or incorrect data
		Inadequate flow measurement	Unreliable effluent SS and/or SBOD due to unavailable or incorrect data
		Inadequate flow splitting	Unreliable effluent SS and/or SBOD due to uneven flow distribution to process
		Wastewater characteristics limit treatability	Inadequate removal of SBOD or TSS
Emergency Systems	130	Lack of alarm system	Process upset due to equipment failure
		Lack of unit bypass	Process upset due to equipment failure
		Lack of standby units for key equipment	Process upset due to equipment failure

Figure 4-2. **Decision-making approach for selecting a modification for an existing facility.**


Design Factors Limiting POTW Performance Identified
Potential Facility Modifications
• Modification 1
• Modification 2
• Modification 3
Eliminate Modifications Limited By Existing Site Conditions
Eliminate Modifications Incompatible With Existing Process or Facilities
Eliminate Modifications That Are Not Cost Effective
Level I Decisions
Level II Decisions
Preference for Modifications That Provide Flexibility In Operations
Preference for Modifications That Benefit Other Processes
Preference for Modifications With Proven Reliability
Increasing Judgment
Select Facility Modification
Implement Facility Modification
Optimize Modified Facility

4.2 Preliminary/Primary Treatment Processes

Improperly operated or poorly designed preliminary and primary unit processes often contribute to problems encountered in the secondary treatment unit processes that result in plant non-compliance. The processes that can impact overall plant performance in this fashion include flow equalization, screening, grit removal, and primary clarification. In addition, POTWs that receive septage can experience problems if the plant was not designed to adequately handle this type of waste. Table 4-2 summarizes design limitations/corrective modifications that are prioritized based on their potential for achieving improved performance. Modifications with proven reliability and those that are less construction intensive appear at the beginning of the listing.

Table 4-2. **Preliminary Treatment/Primary Treatment Design Limitations and Potential Modifications**

Design Limitation/Potential Modification	Page. No.
Flow Control	
4.2.1 Excessive Flow/Load Variations	67
4.2.1.1 Pump Station Modification	68
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Grit Removal	
4.2.4 Inadequate Grit Removal Equipment	72
4.2.4.1 Horizontal-Flow Grit Chamber	72
4.2.4.2 Aerated Grit Chamber	72
4.2.4.3 Vortex Type Grit Chamber	72
Primary Clarification	
4.2.5 Undersized Basin	72
4.2.5.1 Relocation of Recirculation or Secondary Sludge Flows	73
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4.2.5.3 Flow Splitting and Control	73
4.2.5.4 Additional Clarifier	73
4.2.6 Inadequate Sludge and Scum Removal	73
Septage Handling	
4.2.7 Inadequate Septage Handling Facilities	73
4.2.7.1 Separate Treatment	73
4.2.7.2 Septage Receiving Station	74

4.2.1 Excessive Flow Variation

Hydraulic surges, such as those resulting from infiltration or inflow, can adversely affect the performance of practically every unit process, sometimes to the point of non-compliance. These variations can be aggravated by operational factors such as the on-off operation of constant speed pumps or the recirculation of flows within the plant. Operational changes can frequently decrease these impacts. The following examples illustrate this point:

- Constant speed pumps in an influent pump station can be throttled to operate at a lower flow rate over a longer period of time. This practice will increase the water level in the wet well and sewer; consequently, potential adverse effects should be evaluated before implementing this procedure.

- The step feed and contact stabilization modes can be used to alleviate the impact of excessive I/I on suspended growth treatment plants (see Section 4.4).

- Anaerobic digester supernatant can be returned to the plant flow stream during low flow periods (e.g., during the night).

If operational changes do not provide the degree of flow and load stability required, modifications will be necessary. The following discussion includes potential modifications for equalizing flow and loading to a treatment plant.

4.2.1.1 Pump Station Modification

Diurnal variations exhibited by domestic wastewater flows are often compounded by lift stations equipped with constant speed pumps. Modifications to reduce the hydraulic surges caused by the on-off operation of these pumps include:

1. using a recycle system for variable flow control
2. replacing the constant speed pumps with adjustable speed pumps
3. replacing the constant speed pumps with screw pumps
4. using multiple constant speed pumps

A recycle system with constant speed pumps can achieve variable flow control for some applications. A flow diagram of this concept is shown in Figure 4-3. When the constant speed pump turns on, water is pumped from the wet well to a flow control structure. Excess flow is recycled back to the wet well by using an adjustable weir. The weir can be adjusted manually or, if more precise control is desired, automatically using a control system incorporating a flow set point and the wet well liquid level. A pump recycle system could also be installed utilizing control valves instead of a flow control structure.

Replacing constant speed pumps with adjustable speed pumps or screw pumps can also be used to dampen hydraulic surges. Additionally, installation of multiple constant speed pumps of a lower capacity can be used to minimize the magnitude of hydraulic surges. Implementation of any of these pumping modifications will reduce the impact of on-off operation but the diurnal variations will continue.

Equipment commonly used to achieve adjustable speed control include: 1) mechanical speed drives, 2) adjustable frequency drives, 3) adjustable voltage drives, 4) wound-rotor induction motor with liquid rheostat, 5) eddy current coupling, and 6) hydraulic coupling. The selection of the appropriate type of speed control is dependent on desired speed range, cost, equipment mounting, compatibility with existing motor, and efficiency. The main advantage of an adjustable speed pump is the ability to match pumping rate with the influent flow rate. Space requirements are typically less than that for either screw pumps or multiple constant speed pumps. Disadvantages include capital cost and specialized maintenance requirements. Additional information can be found in other sources (1-3).

Replacing constant speed pumps with screw pumps requires major structural changes. These pumps are advantageous in that they do not require a conventional wet well, and they automatically lift variable wastewater flow up to the design capacity of the pump. Screw pumps require more space and are generally limited to applications where the pumping head does not exceed 30 feet. Additional information can be found in other sources (1,3).

Installation of additional smaller constant speed pumps will require structural changes if space has not been provided. Multiple constant speed pumps have simple controls and are less expensive than other pump options. The major disadvantage is the limited flow matching capability of this option relative to those mentioned above.

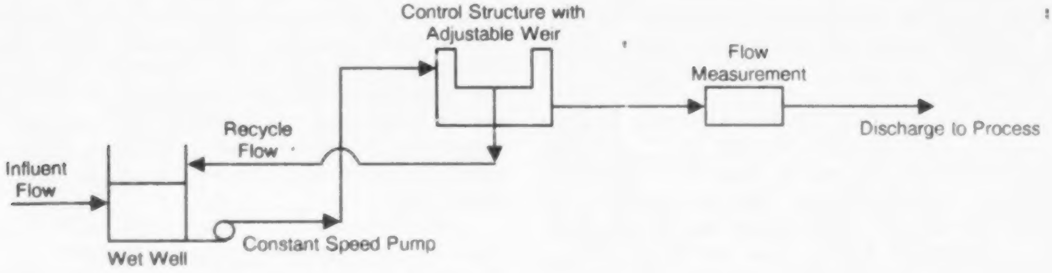
4.2.1.2 Flow Equalization Basin

An equalization basin temporarily stores flow in excess of a pre-set value and returns the stored wastewater to the plant flow stream during low flow periods. Additionally, equalization of organic and toxic compounds is accomplished, thereby dampening the impact of these loads on downstream processes. Since major construction is typically involved, this option should be evaluated relative to increasing the size of other unit processes.

Installation of an equalization basin is dictated by the unique characteristics of each plant. Plants with adequately sized primary treatment facilities should consider locating the unit between the primary and secondary treatment processes. This will result in fewer problems with solids deposition and scum accumulation. If primary clarifier performance is a consideration, the unit should be installed following the plant headworks. At this location, consideration must be given to providing aeration and mixing equipment.

If the major cause of flow variability is an industrial contributor, the preferred location for an equalization basin is at the point of discharge. This allows for a

Figure 4-3. Recycle system for variable flow control.



smaller basin since only the point source flow would need to be considered when sizing the basin.

Equalization basin sizing is dependent upon the degree of equalization desired. The basin can be sized to equalize dry weather diurnal flows or wet weather flows (e.g., infiltration/inflow). In addition, the basin can be sized to receive the total flow stream (in-line basins) or only flow that is above the daily average plant flow (side-line basins). Since side-line basins only handle those flows in excess of the daily average, the required tank size and pumping requirements are less than those of in-line units. In-line equalization basins dampen the variability in constituent concentration to a greater degree than side-line units.

The methods for calculating the size of an equalization basin are described elsewhere (4,77). Typically, a volume equivalent to 10-20 percent of the average daily dry weather flow is required for total flow equalization. The design volume must be increased to accommodate any recycle streams that are intended to pass through the equalization basin. In addition to size, design considerations include basin construction, air and mixing requirements, pumping and control systems, solids removal, and cleaning. Flow equalization can be achieved by utilizing existing tankage or by constructing new metal or concrete tanks or earthen basins. Existing tankage may not be adequate for equalizing flows totally but often can improve the situation such that compliance is achieved. If a new flow equalization basin is proposed, an analysis of concrete, metal, or earthen basin construction should include space availability, ground water level, ground-water protection, basin enclosure, capital cost, and O&M requirements.

Flow equalization basins prior to primary clarification are provided with aeration and mixing equipment to prevent septic conditions and deposition of solids. For normal domestic wastewater, aerobic conditions can be maintained by supplying 0.16-0.25 L/m^3/s (1.25-2.0 cfm/1,000 gal) of wastewater. For example, to satisfy an oxygen uptake rate of 8 mg/L/hr would require about 0.23 L/m^3/s (1.8 cfm/1,000 gal), given a 10 percent standard oxygen transfer rate. If return process streams are to pass through the equalization basin, the aeration requirements must be modified to account for this additional oxygen demand. Mixing requirements for domestic wastewater are 0.004-0.008 W/L (20-40 hp/mil gal) storage.

Normally, because of head requirements, pumping will be required preceding, following, or in some cases, both preceding and following the equalization basin. Flow measurement devices, control valves, and instrumentation are required to divert and release wastewater to and from the equalization basin.

Flow equalization facilities provide significant benefits relative to certain unit process operation and performance. Peak overflow rates at downstream clarifiers are equalized, thereby improving solids removal capabilities. Return activated sludge pumping rates can be held at a more constant level. Where chemical addition is used, equalized flow allows for greater control of dosages and lower chemical costs. Disadvantages are capital cost and additional operational and maintenance requirements. In some plants, it is more advantageous to use an existing aeration basin as an equalization basin even though it reduces aeration time, especially with extended aeration plants with dual aeration.

The following case history illustrates the application of the flow equalization process to an existing wastewater treatment plant.

Case History - Frisco, CO Sanitation District Wastewater Treatment Plant

The Frisco wastewater treatment plant serves a summer and winter recreational area located in Summit County, Colorado. Peak hourly flow to the plant frequently exceeded twice the average daily flow during the winter ski season. In addition, constant speed pumps were used to transfer incoming wastewater to the 32.9-L/s (0.75-mgd) activated sludge plant. The expansion of the plant to 52.6 L/s (1.2 mgd) included the addition of an aerated flow equalization basin. The basin was designed to equalize 100 percent of the daily average flow, and additional volume was included for storage of sludge thickening filtrate water and backwash water from tertiary treatment.

A flow diagram for the modified Frisco plant is shown in Figure 4-4, and design criteria for the flow equalization system are shown in Table 4-3. Following the headworks, the wastewater flows by gravity to a wet well. At this location, peak flows can be diverted to a flow equalization basin. Two constant speed pumps transfer the wastewater from the wet well to the aeration basin. Aeration basin effluent flows by gravity to a secondary clarifier. Secondary clarifier effluent then flows to a tertiary treatment facility for phosphorus removal.

A flow control valve/flow meter arrangement following the raw wastewater wet well is used to control the flow rate to the aeration basin. These devices are used to limit the pump output to not exceed the selected set-point. Excess wastewater in the wet well flows through the overflow pipe to an equalization basin wet well. Two pumps transport this excess flow to the equalization basin. If the water level in the raw wastewater wet well decreases below a set-point, a second control valve on the equalization basin outlet pipe opens to allow stored wastewater to flow back to the raw wastewater wet well.

Expansion of the aeration basin and clarifier was avoided by the addition of the equalization basin. Capability was included to operate the activated sludge system in the plug flow, contact stabilization, and step feed operational modes.

4.2.2 Inadequate Flow Splitting and Control

Flow splitting is often required in treatment plants, especially at larger facilities that utilize multiple basins. A symmetrical design is often utilized to evenly distribute the flow to multiple units and typically no means are provided to control or measure each flow stream. If flow splitting between units is not even, the hydraulic capacity of one of the treatment units and thus the performance can be affected (e.g., solids loss from a secondary clarifier).

Ideal flow splitting flexibility requires: 1) a flow control structure, and 2) flow measurement. Flow control can be incorporated into an existing facility through the addition of adjustable control weirs or appropriate valves (e.g., plug) to each flow stream. If a control weir structure can be utilized, flow measurement can be estimated by measuring the height of water over the weir. In situations where control valves are utilized, some type of meter (e.g., magnetic) or a downstream control structure (e.g., effluent weir from each aeration basin) is necessary.

At plants that include a Parshall flume immediately prior to flow splitting to two treatment trains, the insertion of a thin splitter wall into the throat of the flume can provide reasonably accurate flow distribution. This type of arrangement, shown in Figure 4-5, requires construction modification to the existing exit channel and the addition and support of the splitter wall in the flume. A potential problem with this arrangement is the accumulation of rags on the splitter wall.

4.2.3 Inadequate Screening Equipment

The plugging of sludge pipelines, valves, and pumps are typical problems at treatment plants that have inadequate screening equipment. These problems can ultimately limit overall plant performance in addition to greatly increasing O&M requirements.

Screens utilized for preliminary treatment are generally classified as either coarse or fine, depending on size of the screen opening. Manually-cleaned coarse screens typically have openings of 25-50 mm (1-2 in) and are inclined 30-45 degrees from the vertical. Mechanically cleaned coarse screens have openings of 13-38 mm (0.5-1.5 in) and are inclined 0-30 degrees from the vertical. Approach velocities of 0.6-0.9 m/s (2-3 fps) are recommended, however, to minimize penetration of debris at peak flows, velocity between bars should not exceed 0.9 m/s (3 fps) (5). If fine screens are used for preliminary treatment, they are typically located after a coarse screen. Openings for fine screens range from less than 0.25 mm (0.01 in) to about 6.4 mm (0.25 in), and they can be fixed or utilize a rotating drum. Once screenings have been removed, reintroducing them into the wastewater is not recommended.

Comminutors retain solids on a screen and shred them until they become small enough to pass through the screen openings [typically 6.4-9.6 mm (1/4 to 3/8 in)]. For maintenance purposes, comminutors are usually located in parallel with a manually cleaned screen. Comminutors contribute unnecessarily to downstream loading and maintenance problems when operational and are relatively expensive to repair.

4.2.3.1 Coarse Screens

Practically all wastewater treatment plants are equipped with some type of coarse screening device such as trash racks, manually cleaned screens, and mechanically cleaned screens. If an existing plant headworks utilizes only a trash rack or a coarse screen with large openings [e.g., 50 mm (2 in)], the headworks could be modified by the addition of a manually or mechanically cleaned coarse screen with smaller openings. The new screen could either replace or follow the existing screen. Manually cleaned screens, because of their operational requirement, are typically only used in treatment plants with capacities less than 44 L/s (1 mgd). Mechanically cleaned screens are extensively used for

Figure 4-4. Flow equalization system for Frisco, CO WWTP.

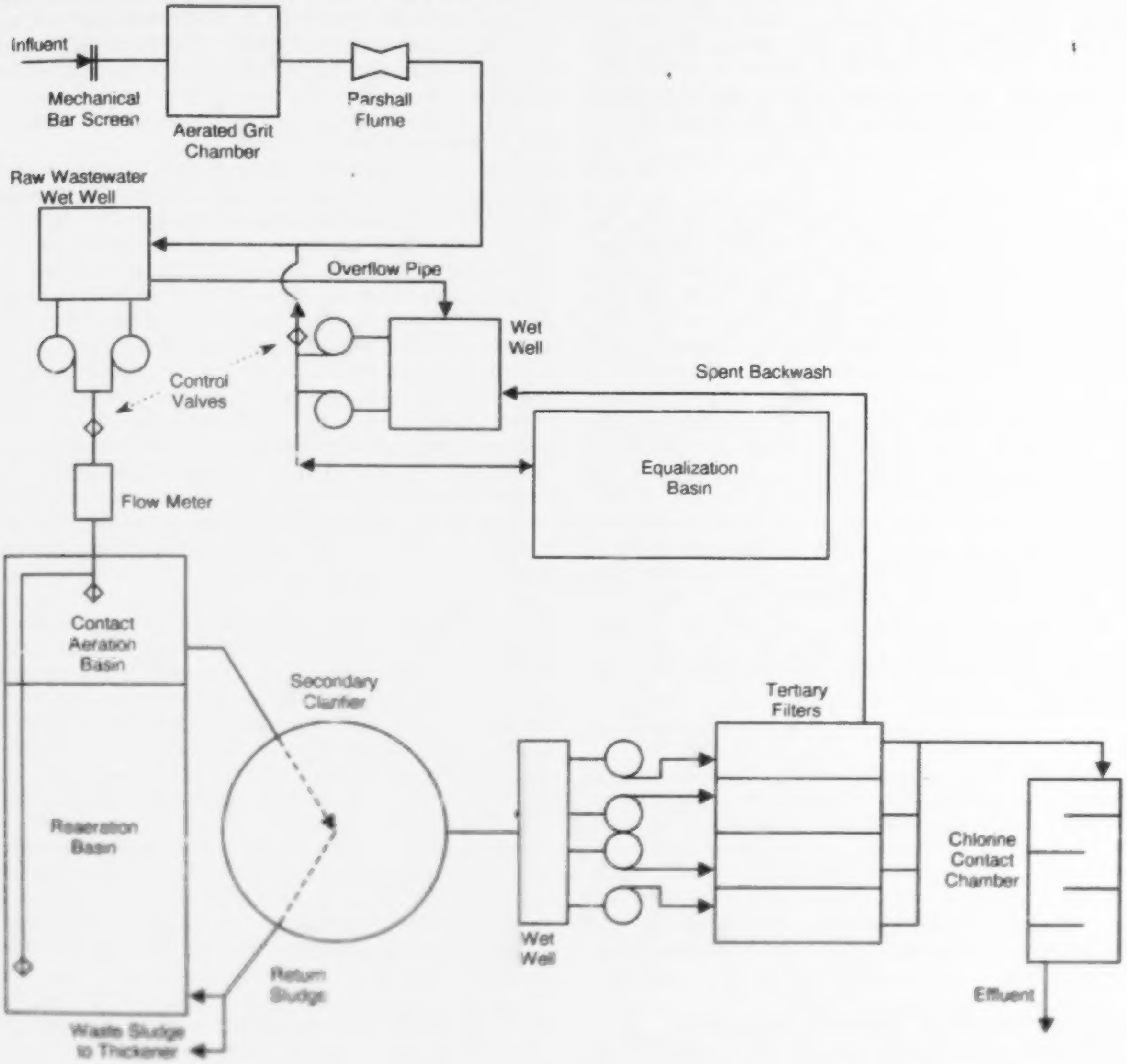
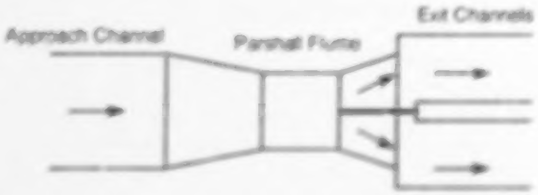

Influent
Mechanical Bar Screen
Aerated Grit Chamber
Parshall Flume
Raw Wastewater Wet Well
Overflow Pipe
Wet Well
Control Valves
Spent Backwash
Equalization Basin
Flow Meter
Contact Aeration Basin
Secondary Clarifier
Tertiary Filters
Reaeration Basin
Chlorine Contact Chamber
Wet Well
Return Sludge
Effluent
Waste Sludge to Thickener

Table 4-2. **Design Criteria for Frisco, CO WWTP Flow Equalization System**

Parameter	Design Criteria
Design Capacity, m³/d	4,540
Equalization Basin Volume, m³	
Influent EQ	545
Spent Backwash EQ	628
Sidestream EQ	151
Total EQ	1,324
Equalization Pumps	2 @ 8,720 m³/d each
Control Valves	Motorized Plug Valves
Flow Meter Type	Magmeter
Aeration Type	Flexible Tube Diffusers

Figure 4-5. Flow splitting from a Parshall flume.


Approach Channel
Parshall Flume
Exit Channels

preliminary treatment in all sizes of plants. Several different types of mechanically cleaned screens are available including: chain and rake, reciprocating rake, and cable driven. An extensive review by Melbinger discusses the design characteristics and operating experiences of the various types of mechanically-cleaned screens (78).

4.2.3.2 Fine Screens

Rag and debris removal can be increased through the addition of a fine screen following a coarse screen. A fine screen with openings of 6.4 mm (0.25 in) will tend to remove increased amounts of debris as well as organic material; consequently, the plant should be prepared to handle and dispose of this material. This type of fine screen must be mechanically cleaned.

Extremely fine screens [e.g., openings of 0.25-1.52 mm (0.01-0.06 in)] provide a level of treatment approaching primary. Static and rotating wedgewire screens are included in this category. Because of the small size of screen opening, these screens typically require some type of high pressure water (and often steam) for periodic cleaning. This type of screening can be considered as an alternative to providing primary treatment at an existing plant, even though BOD and SS removals are generally less than in primaries. Additional information can be found in other sources (5).

4.2.3.3 Comminutors

Comminutors can eliminate screenings handling; however, problems can occur with downstream equipment such as pumps and mechanical aerators due to the "recombining" of shredded material. Additionally, comminutors frequently break down because of their working environment and function, thus requiring bypass of the unit. The use of comminutors at treatment plant headworks is not recommended.

4.2.4 Inadequate Grit Removal Equipment

Typically, the presence of grit in a treatment plant will increase operation and maintenance requirements due to the need for equipment replacement and/or for grit removal from basins. However, in some situations, grit accumulation can directly affect plant performance. For example, grit can accumulate in aeration basins and digesters and subsequently reduce the available treatment volume. Individual types of grit chambers are discussed in the following sections.

4.2.4.1 Horizontal-Flow Grit Chambers

In the horizontal-flow chamber, flow velocities of 0.15-0.3 m/s (0.5-1.0 fps) are maintained in a long channel or a square, shallow sedimentation (detritus) tank. This velocity allows the grit to settle out while the lighter organics remain in suspension. The units are designed to provide a detention time of approximately one minute (5). Minimal control and high O&M requirements are associated with these units; consequently, they are usually not considered as an alternative when modifying a treatment plant. If an existing horizontal-flow chamber is ineffective, aerated or vortex type grit chambers can be considered as replacements.

4.2.4.2 Aerated Grit Chamber

Aerated grit chambers create a spiral rolling motion with the addition of air through diffusers located on one side of the chamber. The diffused air can be used as a method of controlling the velocity within the chamber and thereby allows control of the size of particle that will be removed. Because of the spiral flow pattern, grit particles make several passes across the tank bottom, thus improving the chances for particle removal. Hydraulic detention times in aerated grit chambers range from 2 to 5 minutes at the maximum flow rate (5); however, recent research suggests that detention times of 10 minutes or greater should be considered during peak wet weather flow conditions (76). Because of their low head requirements, aerated grit chambers can be a viable alternative for providing grit removal in an existing treatment plant.

If an existing aerated grit chamber is experiencing problems, the installation of longitudinal or transverse baffles or modifying air flow can sometimes improve performance. Specific baffle locations include: 1) adjacent to the grit hopper, 2) near the chamber outlet, and 3) at the inlet to control direction of flow. Since air flow is one of the main parameters affecting the performance of aerated grit chambers, air flow control is essential. Aerated grit chambers should be equipped with a means of controlling the air rates within a range of 1.6-2.6 L/s/m (1-8 cfm/ft) of channel length (2). Air control valves should be provided if none exist. For chambers with several air headers, individual control valves for each air header should be provided.

If grit problems are occuring in a plant and the grit chamber appears to be adequately designed, the problem may be with the grit removal system. Components such as pumps, chain and flight conveyors, screw conveyors, or bucket elevators may be inadequately designed, installed, or maintained.

4.2.4.3 Vortex Type Grit Chamber

Vortex type grit chambers have been introduced within the last ten years. The two principal vortex devices are the PISTA and the Teacup, both proprietary. In both units, wastewater tangentially enters the grit chamber, creating a vortex flow pattern. Grit settles by gravity to the bottom of the unit while the lighter organics remain in suspension.

4.2.5 Undersized Primary Clarifier

Primary clarifiers can contribute to plant performance problems if poor removal efficiencies and resulting increased secondary loadings negatively affect total plant performance. Typically, primary clarifiers with surface overflow rates in excess of 32-48 $m^3/m^2/d$ (800-1,200 gpd/sq ft), based on daily average flow, will have diminished removal efficiencies. Primary clarifiers loaded within the specified range can be expected to achieve 50-70 percent SS removal (2,4).

In some cases, the addition of coagulants to an undersized primary clarifier can improve process efficiency. However, the surface overflow rate of the clarifier should be below about 48 $m^3/m^2/d$ (1,200 gpd/sq ft) to avoid carryover of chemical floc. The coagulants most commonly used in wastewater treatment include lime, alum, ferric chloride, ferrous sulfate, ferric sulfate, and sodium aluminate (2). Other plant modifications to correct an undersized primary clarifier are presented in the following sections.

4.2.5.1 Relocation of Recirculation or Secondary Sludge Flows

Fixed film treatment facilities that require filter recycled flows to pass through a primary clarifier can exert a significant hydraulic load on the clarifier. A modification to move the recirculation flow to a location after the primary clarifier is often warranted. With configurations that utilize common piping for recirculation flows and returning secondary sludge flows to the primary clarifier, consideration should be given to separating these functions. The potential improved performance from eliminating recirculation through a primary clarifier can be evaluated by stopping recirculation flow for a sufficient period, and monitoring SS removals.

If secondary sludge is directed back to an undersized primary clarifier for co-settling with the primary sludge, excessive scouring of the secondary sludge may occur. This situation can result in the accumulation of solids in the secondary treatment process and, eventually, degradation of plant performance. Other methods of secondary sludge thickening should be investigated. Section 4.6.2 provides information on sludge thickening alternatives.

4.2.5.2 Flow Equalization

The addition of flow equalization facilities can improve performance of a primary clarifier by providing a consistent hydraulic loading rate. The addition of flow equalization facilities to a treatment facility will also benefit other treatment process. Information on flow equalization can be found in Section 4.2.1.2.

4.2.5.3 Flow Splitting and Control

In situations where multiple primary clarifiers are utilized at a plant, inadequate flow splitting could overload some of the units. Refer to Section 4.2.2 for information on flow splitting and control.

4.2.5.4 Additional Clarifier

In treatment plants where the existing primary clarifier is experiencing high surface overflow rates and/or poor removal efficiencies, the construction of an additional clarifier should be evaluated. Design information can be found in other sources (2,4).

4.2.6 Inadequate Scum and Sludge Removal

Inadequate removal of scum from primary clarifiers can impact downstream processes through additional organic loading and plugging of media surfaces (e.g., rotating biological contactor media). Often large amounts of grease and oils in the treatment plant can be attributed to commercial and industrial users. Pretreatment at the source is usually more effective than plant modifications to reduce the amount of scum. When sludge treatment and disposal capacity is limited in a treatment plant, sludge can frequently accumulate in the primary clarifier resulting in abnormally high sludge blanket levels and reduced clarifier performance. In these situations it becomes necessary to address the sludge treatment and disposal limitations. This topic is discussed in Section 4.6.

If the above factors do not significantly affect sludge or scum removal, modification or replacement of the respective removal equipment may be necessary. Steam removal systems should be capable of operating under extreme (winter) conditions and designed to quickly concentrate the scum for separate removal and disposal. Information on equipment modifications can be obtained from the manufacturers.

Scum removal systems should be capable of operating under extreme (winter) conditions and designed to quickly concentrate the scum for separate removal and disposal.

4.2.7 Inadequate Septage Handling Facilities

Some treatment plants receive waste from septic tanks (septage), vaults, chemical toilets, and sand and grease traps. If the treatment plant is not designed to handle these types of wastes, significant operation, maintenance and performance problems can occur (e.g., increased organic loading). Ideally, only septage from septic tanks treating domestic wastewater should be allowed in most POTWs. Other wastes, such as those from sand and grease traps and chemical toilets, can have a detrimental effect on biological treatment systems and should be handled by separate treatment facilities.

4.2.7.1 Separate Treatment

If organic loading due to septage is negatively impacting plant performance, consideration should be given to separate treatment. Processes utilized for separate treatment include: 1) lagoons, 2) composting, 3) biological secondary treatment, 4) aerobic digestion, 5) anaerobic digestion, 6) lime stabilization, and 7) chlorine oxidation. The *Handbook: Septage Treatment and Disposal* provides information on the design of these various systems (6).

4.2.7.2 Septage Receiving Station

The impact of septage on a treatment plant can be minimized by utilizing a properly designed receiving station. Receiving stations can be located at the treatment plant site or remotely where they discharge into an interceptor. Fundamental components of most receiving stations include: 1) dumping station, 2) flow measurement, 3) screening, 4) grit removal, 5) storage, and 6) odor control. Design considerations for septage receiving stations are outlined in the EPA *Handbook: Septage Treatment and Disposal* (6).

4.3 Fixed-Film Treatment Processes

Fixed-film processes have been installed at many wastewater treatment plants because of their predictable and reliable performance and their characteristic ease of operation. A disadvantage of fixed-film processes is their limited operational flexibility. Because of this characteristic, facility modifications are often necessary before compliance can be reached. This section outlines modifications for trickling filter (TF) and rotating biological contactor (RBC) fixed-film systems, as well as for activated biofilters (ABFs).

Table 4-4 summarizes design limitations/corrective modifications that are prioritized based on their potential for achieving improved performance. Modifications with proven reliability and those that are less construction intensive appear at the beginning of the listing.

4.3.1 Undersized Trickling Filter

Trickling filter plant non-compliance is often related to insufficient media surface area to adequately treat organic loads. There are essentially two approaches that can be taken to address this limitation: 1) reduce the organic load, or 2) increase the size of the filter. Reduction of organic load can be accomplished through operational changes or administrative direction (e.g., pretreatment, sidestream control, and chemical addition to a primary clarifier). These approaches should be investigated before construction-intensive alternatives are evaluated.

Reduction of organic loads from industrial sources can be particularly effective for extending the capacity of an existing facility. Pretreatment processes that remove soluble BOD from the waste stream are the most effective. Pretreatment options are particularly appealing where industrial contributions make up a significant portion of the POTW's organic load. Locating pretreatment processes at the source allows a reduced organic load to be treated. Typically, capital costs are lower with this approach than if capacity has to be provided at the POTW to treat the combined waste stream.

Table 4-4. Fixed-Film Design Limitations and Potentia Modifications

Design Limitation/Potential Modification	Page No.
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The reduction or elimination of certain sidestreams is also effective in reducing organic load. Sidestreams that are often returned to the plant headworks include those from aerobic and anaerobic digestion, decant from thermal sludge conditioning, and sludge dewatering operations. Typically, aerobic digester supernatant is of good quality and can be returned ahead of a trickling filter process without significant increase in organic loading to the process. Supernatant from an anaerobic digester typically contains high concentrations of BOD_5, SS and ammonia nitrogen, and often this sidestream has a detrimental effect on trickling filter performance. Recycle BOD_5 load from thermal conditioning can range from 20 to 40 percent of the plant influent load. If the efficiency of solids removal during dewatering operations is poor, sidestreams from these processes will contain solids that can accumulate in the plant and have a negative effect on plant performance. In some cases, cleaning of the filter media may be necessary following elimination of the sidestream to accurately assess the impact of the sidestream load reduction.

Operational changes to reduce the impact of sidestreams include: 1) optimizing sidestream quality, 2) reducing variability of sidestream return, and 3) land application of the sidestream. With single- and two-stage digesters treating biological sludge, it is generally difficult to obtain a good quality supernatant. In a two-stage digester system, supernatant quality can be optimized by ensuring sufficient settling time for liquid/solids separation. The supernatant drawoff point should be located as far from the sludge feed point as possible to minimize short-circuiting, and not in the scum or sludge. The addition of a telescoping supernatant pipe or multiple drawoff ports will help the operator to accurately locate the best drawoff point; however, even with this flexibility, the quality of supernatant recycle is not easily controlled. This approach should not be expected to significantly improve the performance capability of a fixed-film facility.

The impact of sidestream shock loads can be reduced operationally by allowing the return of the sidestream on a fairly continuous basis or during the night when the incoming BOD_5 loading is low. If the plant has an existing flow equalization basin, or unused tankage capable of being converted for use in flow equalization, these facilities can be used to dampen sidestream shock loads. The better solution for negating the adverse impact of sidestreams on facility performance may be to eliminate their return altogether. In some situations, anaerobic digester supernatant can be handled through co-disposal with the digested sludge (e.g., land application).

Before major modifications are planned, it may be advantageous to add coagulants to a primary clarifier to reduce the organic loading to the fixed-film process. The coagulants most commonly used in wastewater treatment include: lime, alum, ferric chloride, ferrous sulfate, ferric sulfate, and sodium aluminate (2). A special short-term (i.e., two or three months) study on chemical addition to a primary clarifier is recommended to determine the impact on performance and to evaluate the effect of increased sludge production.

If operational and administrative approaches have not produced desired performance, modifications to the fixed-film processes will be necessary. The following sections describe modifications for trickling filters in the order of their ease of implementation and potential for improved performance.

4.3.1.1 Replacement of Rock Media With Plastic Media

The organic loading capacity of a trickling filter can be increased by replacing rock media with plastic media. Common rock media has a unit surface area of about 43 m^3/m^2 (13 sq ft/cu ft), whereas plastic media designed for BOD_5 removal has a unit surface area of approximately 98 m^3/m^2 (30 sq ft/cu ft). Owners of rock trickling filters can effectively cut their current organic loading rate in half by replacing the rock with plastic media. Some plastic media with a specific surface area greater than 131 m^3/m^2 (40 sq ft/cu ft) have demonstrated tendencies for media plugging and limited oxygen transfer (10).

Plastic trickling filter media comes in four basic forms: cross-flow, vertical-flow, tubular, and random dump. Cross-flow media consist of ridged sheets that are joined to form an X pattern. Vertical-flow media contain vertical sheets with both wavy and straight patterns. Tubular media consist of only straight vertical tubes. These three plastic media types are constructed of modules of varying volume. Random dump media comes in a variety of sizes and shapes, and the largest dimension of each module is generally less than 20 cm (8 in). Comparative testing has been completed on these various plastic media types (8,28,90). These test results provide information on oxygen transfer, plugging, wetting characteristics, and loading rates.

Two approaches have been generally used to design trickling filters. The first relies on the performance of similar systems (i.e., the NRC equation). The second approach is based on kinetic equations (i.e., the modified Velz equation). This approach was used to characterize the relative performance of six different media types under a variety of loading conditions (8). A recently developed model predicts soluble BOD_5 removal in a trickling filter for several cross-flow and vertical-flow media types under many loading and design conditions (28,29). This model suggests that soluble BOD_5 removal is largely governed by the mass transfer of organic compounds to the biofilm surface and not by substrate kinetics. Model predictions compared favorably with various pilot- and full-scale trickling filter studies.

Total media replacement enables the owner to evaluate the need for renovation of the ventilation and underdrain systems. The clay block underdrain system typically used in rock filters may not be capable of providing the greater ventilation requirements of plastic media filters. When modifying through total media replacement, the clay block underdrain system should be removed and a new support structure installed. For plastic block module use, a simple underdrain and support structure can consist of 15-cm (6-in) wide concrete beams spaced at 60 cm (2 ft) on center, with the beams themselves supported by short concrete walls or piers (10). Random media is generally supported by metal grates (aluminum or stainless steel) placed on top of short concrete walls. The air inlet ports at the base of the filter should be sized to provide adequate natural ventilation throughout the media. As a rule-of-thumb, 1 sq ft of ventilating area should be provided for every 10 to 15 ft of filter periphery, with a minimum of 1 ft provided for a plenum at the filter bottom (2).

Depending on the size of the trickling filter, the rock media can be removed either by hand, by clamshell bucket and crane, or by conveyer. If a clamshell bucket is being used, the bottom layers of rock and debris should be removed by hand to avoid damage to the underdrain blocks. Any remaining material (e.g., rock fragments and biological solids) can be flushed out with a high pressure hose and water. A relatively new technique utilizing a concrete-type pump has been used to remove rock media from trickling filters. This method is relatively fast and avoids any potential damage to the underdrain system that could be caused by a clamshell.

Corrugated sheet media is installed by transferring the block modules by conveyor into the basin and then stacking them by hand in a herringbone pattern. Blocks that go along the perimeter of the basin must be cut to conform to the basin's shape. Random media is typically "dumped" into the basin using a bucket and crane. The media must be gently dumped since it has a tendency to break apart if handled roughly. Additional random media will be necessary to "top off" the trickling filter after settling occurs.

4.3.1.2 Increase Height of Existing Trickling Filter

Increasing the height of an existing trickling filter could provide additional capacity. Considerations for this modification include: 1) additional pumping requirements, 2) structural integrity of the existing media and underdrain systems, 3) available ventilation capacity, and 4) structural integrity of the existing foundation. For rock filters, the addition of rock media above the existing media surface may be limited because of support limitations of the underdrain system. Additional height can readily be achieved by utilizing plastic media; however, the ventilation requirements for the plastic media should be compared with the available ventilating area.

4.3.1.3 Additional Fixed-Film Facilities

Additional fixed-film facilities, either in parallel or series, can be added to an organically overloaded trickling filter facility. Adding a trickling filter in parallel has the advantage of not significantly changing the hydraulic grade line. However, a flow splitting structure would be necessary to distribute the loading to each filter.

If a two-stage (i.e., series) fixed-film process is added, the option may exist to include an intermediate clarifier, as shown in Figure 4-6. New construction of two-stage, fixed-film systems often includes the installation of intermediate clarifiers to remove SS before applying the effluent to the second-stage unit. The benefits are not definite, however, since many two-stage plants function well without an intermediate clarifier. A prudent approach would be to design the modification so that it can be constructed with or without the intermediate clarifier. During initial construction, only the additional fixed-film unit would be installed. If the desired performance is achieved, construction of the intermediate clarifier is avoided. If the desired performance is not attained, the additional clarifier can be added.

RBCs represent an option for adding additional fixed-film capability. Because of the difference in head requirements, RBCs would typically be more appropriate in a series configuration with a trickling filter than in a parallel one. As a general guideline, RBCs shouldn't be used as upstream roughing filters since the first RBC stage must not become organically overloaded, causing treatment and equipment structural problems (16). If the two-stage, fixed-film process is to include RBCs, the design should provide for soluble BOD loads to the RBCs first stage below 12.2 kg/1,000 m^2/d (2.5 lb/d/1,000 sq ft) of media surface area (7). RBCs are often cited as requiring less area than conventional trickling filters, however, plastic media block modules have allowed the construction of trickling filters as high as 12 m (40 ft). Additional information on RBCs is included in Section 4.3.6.

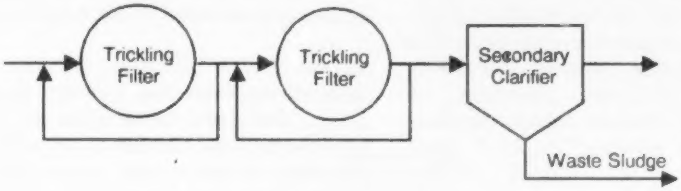
The additional second-stage process can be located either upstream or downstream of the existing trickling filter, depending on the physical constraints of the plant and the physical condition of the existing filter. If plugging or lack of ventilation is a problem with an existing rock filter, consideration should be given to locating the additional process in front of the rock filter. The upstream location will serve to reduce the organic load to the downstream trickling filter. Information on design approaches for trickling filter plastic media is included in Section 4.3.1.1.

4.3.1.4 Trickling Filter/Suspended Growth Systems

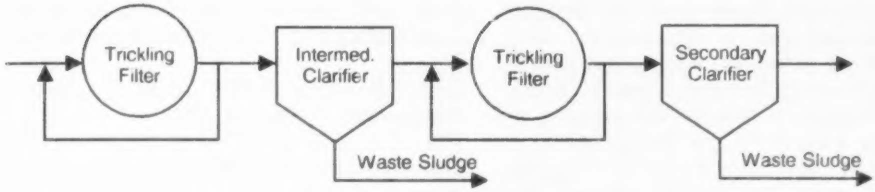
Addition of a suspended growth system at an existing trickling filter plant has been effectively used to improve fixed-film facility performance. Examples of such systems include the trickling filter/solids contact (TF/SC), trickling filter/activated sludge (TF/AS), roughing filter/activated sludge (RF/AS), and biofilter/activated sludge (BF/AS) processes (12). The basic difference between these processes is the relative sizes of the trickling filter and aeration basin.

A trickling filter plant that is able to adequately remove soluble BOD (i.e., effluent $SBOD_5$ from the filter of less than 15 mg/L) but is having problems with dispersed solids in its effluent could benefit from a conversion to a TF/SC system. The basic components of the TF/SC process typically include one or two small aeration tanks interposed between the filter, secondary clarifier with an influent flocculating structure and return activated sludge facilities. The solids contact portion of the process provides for improved solids capture and removal of particulate BOD. The mechanism by which this improved treatment occurs is the contact of unsettled trickling

Figure 4-6. Flow schematics of two-stage fixed-film processes.



a. Two-Stage Without Intermediate Clarifier



b. Two-Stage With Intermediate Clarifier

filter effluent with well-flocculated trickling filter solids. Possible configurations for the TF/SC process are presented in Figure 4-7 (13). The selection of which mode to utilize at a specific plant is dependent on the particulate and soluble BOD removal requirements. Mode A is the best choice if significant soluble BOD_5 and particulate removal is required from a trickling filter effluent. Mode B is recommended if particulate removal is the main requirement, and Mode C works best when particulate removal and a limited amount of soluble BOD_5 removal is necessary (13).

The hydraulic retention time (HRT) in the solids contact basin should be 1 hr or less based on the combined trickling filter and return sludge flows (13). As such, the modification of a trickling filter plant to a TF/SC system can be accomplished by constructing a small aeration basin after the filter or by routing the filter effluent to an abandoned basin that has been provided with aeration. This latter approach was successfully taken at the Springfield, Oregon wastewater treatment plant where an abandoned grit channel was converted into a biological contact channel and a small sludge reaeration tank was installed (12,91).

A TF/SC system can provide improved reduction in soluble BOD_5. At the Longmont, Colorado wastewater treatment plant, 30-40 percent of the $SBOD_5$ that enters the solids contact unit is removed (9). The solids contact system at Longmont includes an aerated solids contact tank (HRT = 6 minutes), a return sludge aeration tank (HRT = 12 minutes), and flocculating center wells in the secondary clarifiers (HRT = 27 minutes). Soluble BOD_5 enters the solids contact process at a concentration of 8-15 mg/L and exits the process at a concentration of 5-7 mg/L. Though this effluent quality is better than that required for secondary treatment, it indicates the potential $SBOD_5$ removal capability of the TF/SC process.

To benefit fully from the TF/SC modification it is necessary that the aerated biological solids be introduced into the secondary clarifier in a gently stirred, flocculant condition. If effluent from the aeration tank is agitated due to pumping conditions or by being rapidly introduced into the secondary clarifier, the SS may become redispersed. Original TF/SC center well designs called for installation of a flocculating mechanism that would gently stir the mixed liquor as it entered the center well. Experience with the process has shown that the action of wastewater flowing into the center well can be sufficient to create the gently stirred environment and that the flocculating mechanism may not be needed. In fact, at the Longmont wastewater treatment plant, effluent SS were higher during periods when the flocculating mechanism was activated than when the mechanism was turned off (14). A more detailed discussion of the factors to be considered when modifying a suspended growth clarifier is provided in Section 4.4.

In more severe organic overloading cases, the TF/SC modification will not remove the required amount of soluble BOD and an aeration basin with a longer HRT and MCRT will be necessary. Depending on the specific situation, the RF/AS, TF/AS, or BF/AS process could provide the additional required treatment. Research indicates that combined system designs should be based on reliably achieving a specific effluent nonsettleable SS concentration (103). This research suggests that effluent nonsettleable SS are largely undegraded particulate organics present in the influent wastewater and that removal of nonsettleable SS occurs by bioflocculation. System nonsettleable SS removal is affected by both total organic loading to the filter and MCRT in the suspended growth system.

With the RF/AS process (see Figure 4-8), the aeration basin is generally one-quarter to one-half the size required for conventional activated sludge, but 3 to 7 times larger than the contact channel used in TF/SC (12). Additional information on the RF/AS process is presented in Section 4.4.4.2. In the BF/AS process (see Figure 4-8), return activated sludge is recycled over the filter rather than passing directly to the aeration basin. Opinions differ as to the advantages of operating a combined trickling filter and activated sludge system as a RF/AS rather than a BF/AS process. Many designers include the flexibility to operate either way because the expense of adding the necessary piping is usually minor (12). Additional information, including a case history, on the BF/AS process is included in Section 4.4.4.2.

In the TF/AS process, an intermediate clarifier is located between the trickling filter and the aeration basin. The need for removal of trickling filter solids in an intermediate clarifier is not well established. On the contrary, research has shown that the introduction of these solids into the suspended growth stage provides improved sludge settleability characteristics (31). Because of these concerns, the TF/AS process has been used less than the RF/AS or BF/AS process. A case history of a TF/AS plant is presented below.

Case History: Fort Collins, Colorado TF/AS Wastewater Treatment Plant

The City of Fort Collins, Colorado modified their existing wastewater treatment plant to a TF/AS facility through the addition of a new short-term aeration basin and secondary clarifier. The modified plant is shown in Figure 4-9. Design parameters are included in Table 4-5. The existing plant included headworks facilities, primary clarifiers, a rock trickling filter, a final clarifier, disinfection facilities, and anaerobic digesters. The plant was modified to the TF/AS process by

Figure 4-7. Three modes of operation for the trickling filter/solids contact (TF/SC) Process.

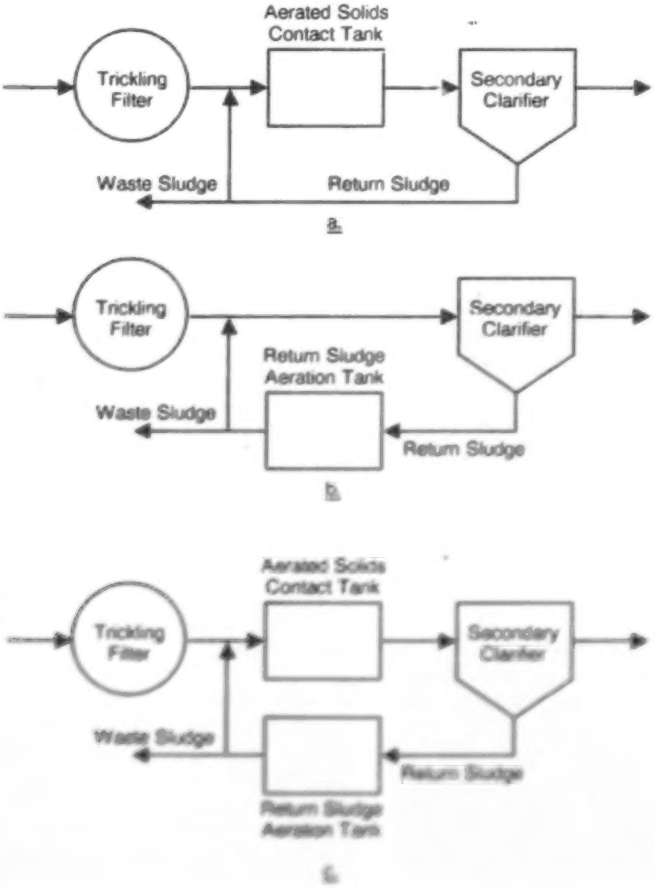
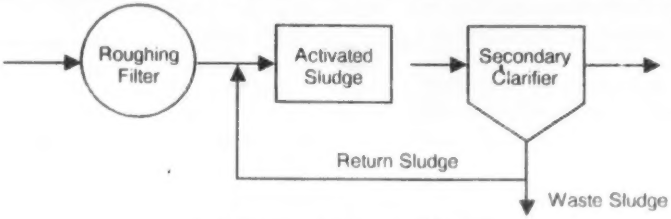
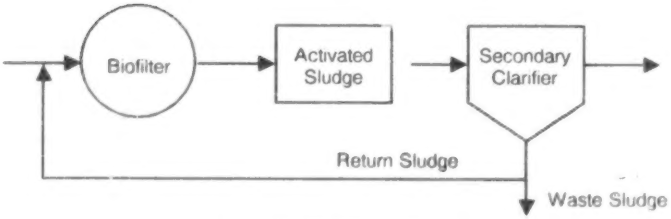

Aerated Solids Contact Tank
Trickling Filter
Secondary Clarifier
Waste Sludge
Return Sludge
a.
Trickling Filter
Secondary Clarifier
Return Sludge Aeration Tank
Waste Sludge
Return Sludge
b.
Aerated Solids Contact Tank
Trickling Filter
Secondary Clarifier
Waste Sludge
Return Sludge
Return Sludge Aeration Tank
c.

Figure 4-8. Flow schematics for the roughing filter/activated sludge and biofilter/activated sludge processes.



a. Roughing Filter/Activated Sludge



a. Biofilter/Activated Sludge

directing flow from the existing final clarifier (now an intermediate clarifier) to a new aeration basin. Effluent from the aeration basin flows to screw pumps where it is lifted to a new secondary clarifier. The plant is base loaded, and excess flow is diverted to a downstream plant also owned by the City.

In 1987, the organic loading to the trickling filter ranged from about 5 to 20 BOD_5 kg/1,000m^2/d (1-4 lb/d/1,000 sq ft) of media volume. During the same period the organic loading to the aeration basin averaged about 0.16 kg $BOD_5/m^3/d$ (10 lb/d/1,000 cu ft). Under these loading conditions, the system performed well with effluent BOD_5 and TSS generally remaining below 10 mg/L (15).

4.3.1.5 Additional Recirculation Capacity

The benefits of trickling filter recycle are reportedly: 1) enhanced removal of complex organic substrates, 2) dilution of BOD_5 concentrations, 3) increased DO content of the wastewater, 4) uniform shear of biological growth to minimize sudden sloughing during seasonal changes, and 5) maintaining a minimum wetting rate for the media during low flows. The magnitude of these benefits in terms of treatment capacity is difficult to quantify. A recently developed model for plastic sheet media actually predicts an increase in $SBOD_5$ as the recycle ratio increases (28), but if it is decided that additional recycle capacity would enhance treatment capability, the following factors should be considered:

- A recycle to influent flow ratio of 2:1 is generally recommended.
- Modification to the distribution and underdrain systems may be required due to the increased hydraulic loading.
- The recirculation system should be configured so that recycle flows do not pass through either the primary or secondary clarifiers.

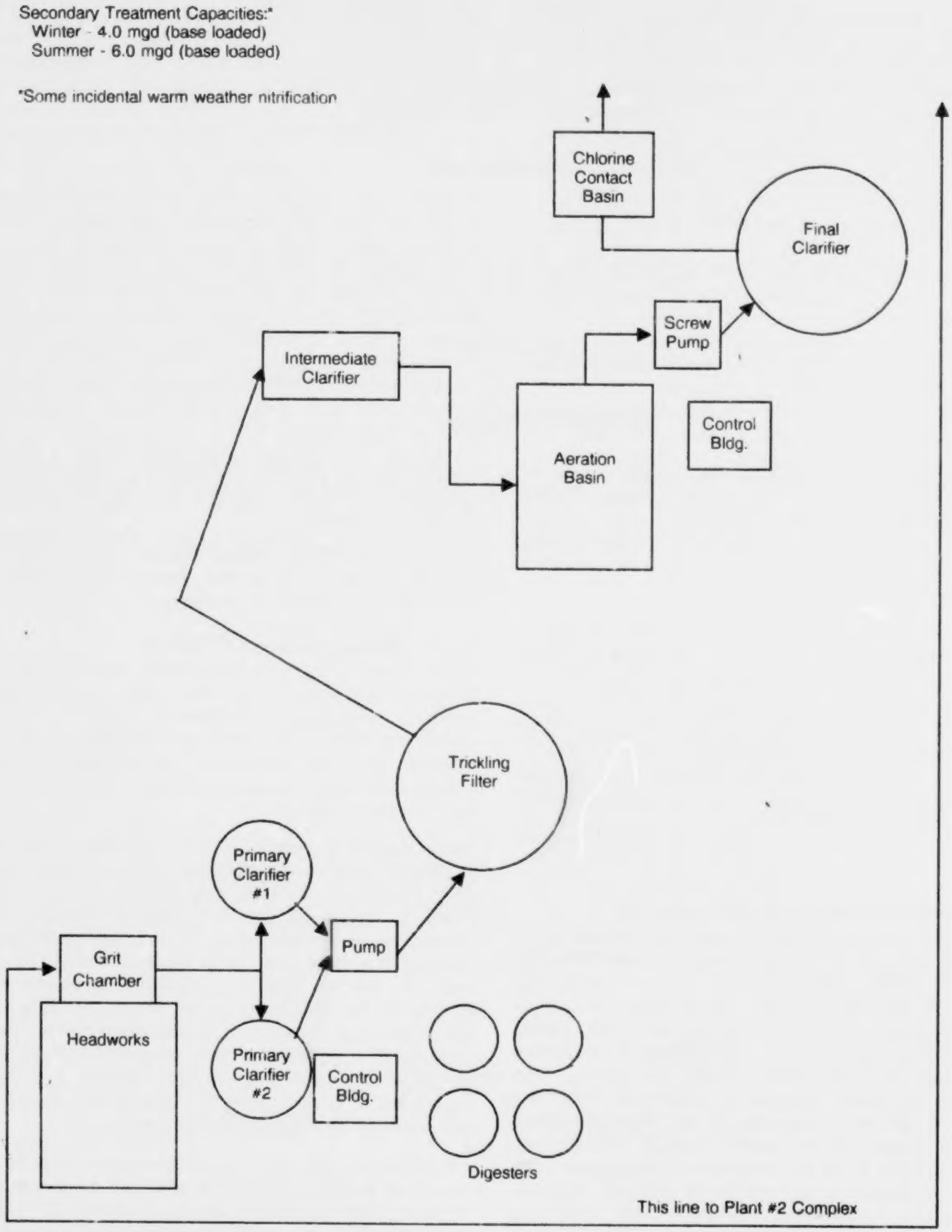
4.3.2 Inadequate Oxygen Transfer

When oxygen transfer throughout the trickling filter media is inadequate, the filter may not be able to achieve the desired performance. Some of the conditions that may lead to inadequate oxygen transfer include degraded rock media, broken underdrains, partially submerged underdrains, and high organic loadings.

Media degradation and broken underdrains can result in ponding and media plugging, both of which impact oxygen transfer. If media degradation in rock trickling filters is limited to the first several inches, or an isolated area of the filter, it may be sufficient to remove the fragments and replace them with new rock. A smoke test is a helpful procedure for identifying the degraded areas within the filter when the extent and location of media degradation are not known. If it is found that degradation is more extensive than the first several inches, total media replacement is warranted. Considerations for this procedure are presented in Section 4.3.1.1.

For proper ventilation, it is recommended that at least 1 sq ft of ventilating area be provided for every 10 to 15 ft of filter periphery and a minimum of 1 ft be provided for a plenum at the filter bottom (2). If this condition is not present, the existence of oxygen limiting conditions can be checked by installing a temporary forced draft ventilation system and assessing its effect on performance. This special

Figure 4-9. Fort Collins, Colorado RF/AS Wastewater Treatment Plant.



Secondary Treatment Capacities:*
Winter - 4.0 mgd (base loaded)
Summer - 6.0 mgd (base loaded)

*Some incidental warm weather nitrification

Chlorine Contact Basin
Final Clarifier
Screw Pump
Intermediate Clarifier
Aeration Basin
Control Bldg.
Trickling Filter
Primary Clarifier #1
Pump
Grit Chamber
Headworks
Primary Clarifier #2
Control Bldg.
Digesters
This line to Plant #2 Complex

Table 4-5. Design Criteria for Fort Collins, Colorado TF/AS Wastewater Treatment Plant

Parameter	Design Value
Design Capacity, mgd	6
Existing Primary Clarifiers	
Number	2
Surface Overflow Rate, gpd/sq ft	530
Existing Trickling Filter	
Number	1
Diameter, ft	130
Depth, ft	5.75
Media Type	Rock
Media Volume, cu ft	76,300
Existing Secondary Clarifier (converted to intermediate clarifier)	
Number	1
Surface Overflow Rate, gpd/sq ft	775
New Aeration Basin	
Number	1
Volume, cu ft	42,200
Detention Time, hr	1.3
New Final Clarifier	
Number	1
Surface Overflow Rate, gpd/sq ft	630

study could be accomplished by utilizing leased portable ventilation fans and plastic sheeting to direct air through the filter underdrain system. If performance improves considerably, forced draft ventilation equipment can be made a permanent part of the trickling filter system. Typically, forced ventilation does not work well with rock filters because of underdrain constrictions. Structural modifications can be made to improve ventilation, such as enlarging the inlet openings into the underdrains. Also, if excessive submergence is caused by filter effluent backing up in the channel due to the absence of freefall conditions at the outlet, structural modifications to the outlet structure or installation of a low head lift station can be considered.

Trickling filters that are oxygen limited due to organic overloads should consider the modifications specified for an undersized unit process, such as media replacement or conversion to a two-stage system. However, if the amount of on-line media is apparently adequate for current organic loads, a forced-draft ventilation system may improve performance. This situation can arise in warm, humid climates where the air density differences aren't sufficient for natural-draft ventilation, or in trickling filters with tall, narrow profiles. An example of a forced-draft installation is found at the Stockton, California wastewater treatment plant where rotary fans were installed to provide an upward air flow through concrete ducts (4).

4.3.3 Inadequate Hydraulic Wetting for TF

The hydraulic wetting rate for a trickling filter is determined by the combined flow of wastewater and recirculated effluent that is directed to the filter. Solids accumulation in the filter can occur in plants that have inadequate hydraulic wetting capability, resulting in decreased BOD removal efficiency and sudden sloughing of solids to the final clarifier. If this deficiency is suspected, various operational practices can be initiated to simulate an increased wetting rate. At plants with multiple filters, all of the wastewater flow can be directed to one filter on a periodic basis (e.g., weekly).

In some cases, increasing the flow to a filter may not be adequate to control the growth of biomass in a filter. Reducing the rotational speed of the distributor may also be necessary. An operational practice called "walking the filter" can be used on small filters to temporarily slow the distributor speed.

One method of accomplishing this procedure involves the plant operator tying a rope or cable to the distributor arm and slowly "walking" the arm around the filter on a periodic basis. If this practice results in improved performance, modifications to the distributor may be advantageous. Experience with flushing intensities for various types of filter media and methods of slowing distributor rotational speeds has been reported by Albertson (110).

4.3.4 Lack of Cold Weather Protection for Trickling Filter

Cold wastewater temperatures result in decreased microbial activity and lower treatment efficiencies. Trickling filters are susceptible to climatic changes because the wastewater is exposed to the ambient air as it percolates through the media. To achieve adequate treatment, trickling filters operating in freezing conditions should be loaded under 7.3 kg BOD_5/1,000 m^2/d (1.5 lb/d/1,000 sq ft) of media surface area. Under non-freezing conditions, loads as high as 11.2 BOD_5/1,000 m^2/d (2.3 lb/d/1,000 sq ft) are appropriate (7).

An approach to increase winter treatment efficiency is to reduce the organic load by modifying the trickling filter as described in the previous section. However, this approach will result in an oversized process during the warmer months. Placing a cover over the trickling filter protects the filter from wind, and retains some of the heat contained within the wastewater. The trickling filter's cold weather treatment capacity can be increased by as much as 50 percent with this modification. Fiberglass covers specifically designed for trickling filters are available but can be expensive. A low cost approach has been taken at several treatment plants in northern Iowa by covering the trickling filters with galvanized grain bins. These prefabricated structures are available in a number of different sizes and are relatively easy to construct and inexpensive. Irrespective of the type of cover utilized, consideration needs to be given to the ventilation requirements for the media. If adequate ventilation is not provided during warm weather, reduced treatment efficiency will likely result.

best copy available

Other low cost measures for cold weather protection include installing wind breaks around the filters, earthen berms against the filter walls, or louvers or doors on the ventilation ports. Although these modifications will not result in any significant increase in filter performance, minor expenditures toward these types of modifications may be justified.

4.3.5 Undersized RBC System

To achieve consistent compliance with secondary treatment standards, the total organic load to an RBC process should be maintained under 2.9 kg $SBOD_5$/1,000 m^2/d (0.6 lb/d/1,000 sq ft) of media surface (7). Measures that can be taken to control the impact of organic loads from influent and sidestream sources should be investigated before modifications to increase the capacity are planned. If these changes are not feasible, modifications will probably be necessary. Modifications include increased media surface area, preaeration and additional biological processes.

4.3.5.1 Additional Media Surface Area

Where space is available, additional RBC trains can be installed parallel to existing units. New or additional pumping capacity should not be required. Since no process changes are made, operational complexity for the plant staff will be minimized.

In some RBC installations, it is possible to increase the total surface area of media by replacing some of the standard density media [9,300 m^2 (100,000 sq ft per shaft)] with high density media [13,900 m^2 (150,000 sq ft or more per shaft)]. To avoid media plugging, high density media should not be used in the first two stages where the greatest biofilm growth is occurring. For some units, it is possible to replace media without removing the shaft from the basin. For others, it will be necessary to lift the shaft out and slide the media off the end of the shaft. RBC manufacturers can provide procedures for these modifications.

An RBC system with fewer than four stages should consider adding shafts to increase the number of stages. It is recommended that influent piping or channels be installed during a retrofitting project to provide the operator with a greater degree of process flexibility (e.g., ability to step feed the various stages, removable baffles between stages, etc.).

4.3.5.2 Preaeration

A recent modification to RBC facilities that are experiencing high $SBOD_5$ loadings or septic influent conditions involves the use of preaeration of the wastewater. At two locations - Woodburn, OR and Granstran, SC - up to 70 percent $SBOD_5$ conver-sion in the influent was achieved in preaeration facilities with detention times of 4-6 hr. In both cases, it was believed that the presence of micro-organisms in the plant influent contributed to the large $SBOD_5$ conversion. Since limited information is available on this modification, pilot studies should be completed before pursuing this alternative (97).

4.3.5.3 Additional Biological Process

Additional biological processes can be used to improve the capability of an RBC system. A trickling filter can be installed ahead of the RBC to serve as a roughing filter or an aeration basin, or a trickling filter can be constructed to operate either parallel to or after the existing RBC. The selection of a second biological process should be site-specific and based on the relative merits of each process. If an aeration basin is added, the existing secondary clarifier that was adequate for a fixed-film process may not be adequate for suspended growth solids separation. An advantage exists when a fixed-film process is followed by a suspended growth process because of the controllability that is associated with the latter process (e.g., mass, dissolved oxygen, return sludge). For further information, the reader is referred to the discussion on two-stage systems in Section 4.3.1.

4.3.6 Undersized First Stage RBCs

Excessive organic loads to the first stage of an RBC process have been identified as the cause of many operational problems and, occasionally, compliance problems. To prevent overload conditions from occuring, the organic load to the first stage should be maintained under 12.2 kg $SBOD_5$/1,000 m^2/d (2.5 lb/d/1,000 sq ft) of surface area and under 29.3 kg $TBOD_5$/1,000 m^2/d (6.0 lb/d/1,000 sq ft) (7). Problems that can arise from an overloaded first stage include:

- excessive growth of biofilm, hindering oxygen and substrate transport
- DO deficit in the bulk liquid
- proliferation of *Beggiatoa* and other nuisance microorganisms
- structural overload and failure of the media and central shaft
- development of septic odors (16)

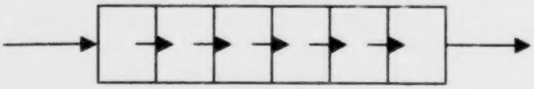
Several of the modifications presented to correct an organic overload to the overall RBC system (e.g., influent and side-stream control and construction of additional biological processes) will reduce the organic load to the first stage and should be considered. Since excessive biofilm growth and oxygen transfer limitations are common in overloaded first stages, conversion to high density media is not recommended. Options that address an organic overload in the first stage include:

- piping or structural changes for load redistribution
- positive control of flow distribution

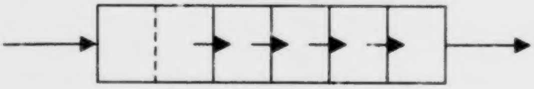
4.3.6.1 Organic Load Redistribution

When the organic load to the first stage exceeds 12.2 kg $SBOD_5$/1,000 m^2 of surface area/d (2.5 lb/d/1,000 sq ft) or 29.3 kg $TBOD_5$/1,000 m^2/d (6.0 lb/d/1,000 sq ft), modifications that allow redistribution of the organic load should be considered. Options include first-stage enlargement, step feeding to the first several stages, and parallel feeding to form two shorter trains from one long, multi-stage train. Flow schematics for these modification options are presented in Figure 4-10.

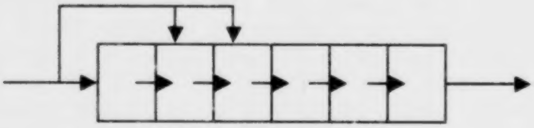
Figure 4-10. Flow schematics for RBC modification options that provide for load redistribution.



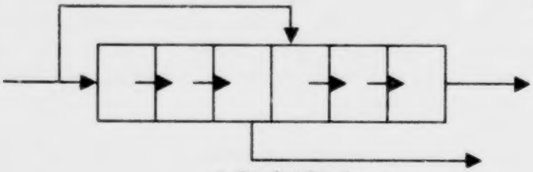
a. Conventional



b. First Stage Enlargement



c. Step Feed



d. Parallel Feed

Since organic load redistribution involves decreasing the load to the first stage by increasing the load to other stages, it will generally be necessary to have at least four stages to successfully implement these modifications. POTWs that have fewer than four total stages should consider the modifications described in Section 4.3.4.

Organic loads can be redistributed by replacing permanent first-stage divider walls with removable barriers made of either wood or metal. Installing a removable barrier allows the option of enlarging the first stage (i.e., establishing more first stage area) by removing the temporary barrier. It is also desirable to install an influent header to redistribute the flow more evenly across the modified first stage. This modification reduces the total number of stages available.

Converting an RBC system from series to parallel flow operation increases the number of first stages and decreases the total number of stages. Conversion to the step feed mode of operation allows for the first stage to be partially bypassed, thereby increasing the organic load to the downstream stages. To convert a series feed system to either a parallel or step feed configuration requires the installation of additional piping and valves, or channels and gates. Provisions should be made for positive flow control and splitting.

4.3.6.2 Positive Control of Flow Distribution

If nonuniform flow distribution exists between multiple process trains, one first-stage unit may be overloaded. Nonuniform flow distribution is common when several trains are fed by one influent channel with slide gate control, especially if the individual first-stage shafts rotate in opposite directions. Uniform flow distribution can be achieved at relatively low cost by installing a splitter box or weirs ahead of each train.

4.3.7 Inadequate Oxygen Transfer for RBCs

Inadequate oxygen transfer is often associated with an organic overload condition, especially in the first stage. Organic overloads contribute to excessive biofilm growth on the media, which in turn plugs air passages and limits oxygen transfer. Facility modifications that address the overload problem, such as step feeding and construction of additional biological processes, are recommended. However, options exist to improve oxygen transfer rather than reducing the organic loading rate. These options should be considered when the cost to reduce the organic load is prohibitive, or when the overload condition occurs on an infrequent basis.

Oxygen transfer can be improved by providing supplemental aeration and variable shaft rotational speed capability. Supplemental aeration has been employed extensively to control biofilm thickness and improve oxygen transfer. In general, it will only be necessary to provide supplemental aeration to those biodiscs that are experiencing overload conditions. To implement the modification, coarse bubble diffusers are placed underneath the media and air is injected at a rate sufficient to promote sloughing [50-100 L/s/m^2 (100-200 scfm/100,000 sq ft of media surface area)].

If the supplemental aeration approach is selected, it is recommended that mass load cells be installed on each shaft. Load cells measure the total shaft weight and can be used to provide an indication of when the combined shaft-biofilm weight is approaching the manufacturer's allowable maximum. In conjunction with load cells, supplemental aeration can be used on an intermittent basis to maintain shaft weights (i.e., biofilm thickness).

Variable shaft rotational speed capability can be used to maintain the thin biofilm that is necessary to allow for good oxygen transfer. Increasing the shaft rotational speed can be used to promote sloughing. This measure will also raise the DO concentration as a result of the increased agitation. This capability only needs to be installed in the first one or two stages. Load cells, which permit monitoring of growth, are recommended to provide additional process control.

In some treatment plants, an oxygen-deficient environment may exist under the standard RBC covers. Provisions should be made for adequate ventilation for both performance and safety considerations.

4.3.8 Inadequate Control With RBC Air Drive Units

Operational problems experienced with air drive RBCs include slow rotational speeds, uneven biomass thickness, "loping" (uneven rotation), and shaft stoppage (17). Modifications that can be made include the installation of larger air cups, provisions for positively measuring and controlling air flow rates, and the installation of hydraulic sprays to assist shaft rotation.

Replacing 10-cm (4-in) air cups with 15-cm (6-in) air cups has been effective at stabilizing rotational speeds and reducing shaft loping and stalling (17). However, excess biofilm growth was not controlled by this measure. Most existing air drive RBCs are not provided with equipment to measure and control air flow rates to the individual shafts (18). Since biofilm growth is different in each stage, installation of such equipment is recommended to allow for better operational control of shaft speeds. Hydraulic sprays have been used to restart stopped shafts (17) and can also be used to shear excess biofilm from the media.

The measures described above can be utilized to obtain the best performance from an air drive system. A more direct approach is to convert air drives to mechanical drive units. This approach is more costly but provides positive control of shaft rotation. If this modification is pursued, consideration should be given to the installation of variable speed drives. The air drives should be retained to provide supplemental aeration capability.

4.3.9 Undersized ABF

The Activated Bio-Filtration (ABF) process is a proprietary system that consists of a fixed-film tower utilizing redwood media and may or may not include a separate aeration basin after the filter. Schematic diagrams of these variations of the ABF system are shown in Figure 4-11. A constant hydraulic loading to the biofilter can be achieved by recycling biofilter effluent or a combination of biofilter effluent and return activated sludge. To achieve consistent compliance with secondary treatment standards, it is recommended that the ABF system include an aeration basin.

Approaches that can be taken to address the limitations of an undersized unit process are: 1) reduce the organic load to the process or 2) increase the effective size of the process. Measures that can be taken to reduce the organic load, such as influent and sidestream control, are described in Section 4.3.1.

To increase the effective size, facility modifications can be directed toward either the biofilter, the aeration basin, or both. To consistently meet secondary standards, organic loadings to the biofilter should be maintained at or below 1.6 kg $TBOD_5/m^3$ of media volume/d (100 lb/d/1,000 cu ft), and the aeration basin HRT, excluding sludge recirculation, should be 4 hr or greater (7).

The treatment capacity of the biofilter can be increased by either increasing the size of the tower so that it can hold additional media or constructing an additional biofilter. Typically, economic considerations (e.g., pumping) and site limitations can be used to determine the best approach.

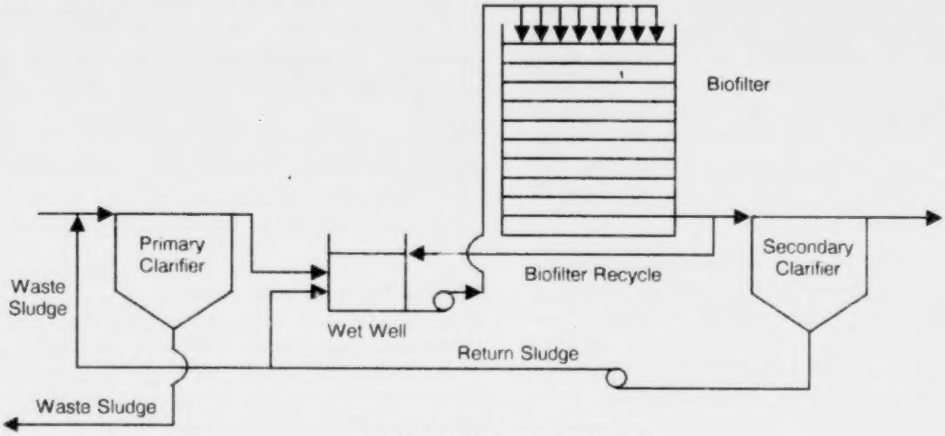
The redwood media in some ABF treatment plants has been replaced with plastic trickling filter media because of operational problems (e.g., deterioration of the media, poor wetting, and severe fungus growth) (19). However, in the absence of these problems, media replacement is not a generally accepted method of increasing a biofilter's treatment capacity. The capacity of a biofilter is typically based on volumetric loadings (lb BOD_5/d/1,000 cu ft) rather than areal loadings (lb BOD_5/d/1,000 sq ft) as with a trickling filter. This difference in loading criteria between biofilters and conventional trickling filters is attributed to the effect that recycled sludge in a biofilter has on BOD_5 removal. Based on this criterion, increasing the specific surface area of the media by replacing redwood with plastic media will not necessarily result in an increase in treatment capacity above design levels.

Increasing the treatment capacity of the aeration basin is the best approach for making a positive change in overall treatment capability. An analysis of data from several operating facilities has indicated that the biofilter only satisfies 17-46 percent of the total system oxygen demand. As such, the overall process performance is directly related to aeration basin capability (20). To increase the capacity of an aeration basin, it is generally necessary to enlarge the existing structure or to construct an additional basin. Procedures and considerations for this type of modification are presented in Section 4.4.

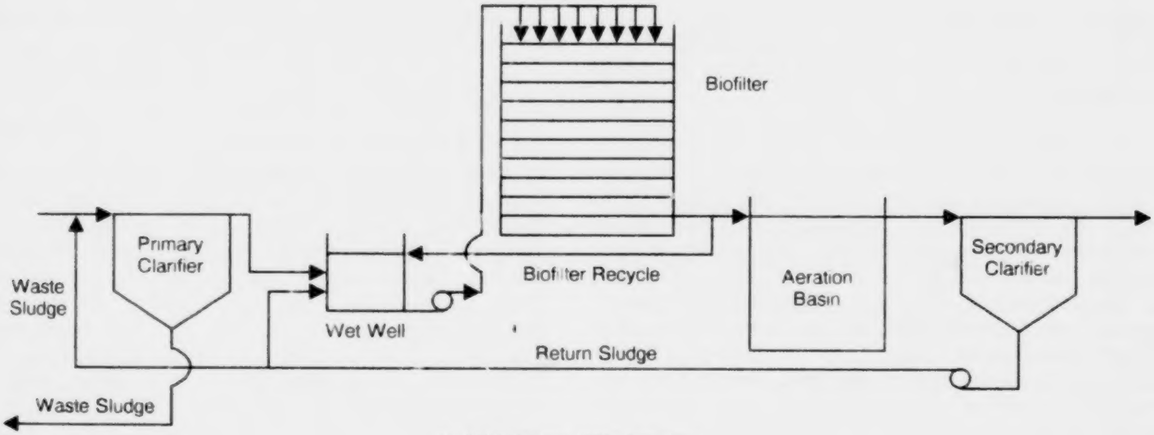
4.3.10 Inadequate Oxygen Transfer for an ABF System

Oxygen-limiting conditions may occur in either the biofilter or the aeration basin. Facility modifications that improve oxygen transfer in a biofilter are generally similar to those for trickling filters. One exception to this similarity is mixed liquor recycle over the biofilter. Since mixed liquor can have a significant oxygen demand, its removal may improve oxygen transfer to

Figure 4-11. Activated Biofilter (ABF) System.


Biofilter
Primary Clarifier
Secondary Clarifier
Waste Sludge
Biofilter Recycle
Wet Well
Return Sludge
Waste Sludge

a. ABF System Without Aeration


Biofilter
Primary Clarifier
Waste Sludge
Biofilter Recycle
Aeration Basin
Secondary Clarifier
Wet Well
Return Sludge
Waste Sludge

b. ABF System With Aeration

the biofilm. Media degradation is usually not a cause of poor oxygen transfer unless severe redwood deterioration has occurred. In such a situation, however, the reduction in effective treatment volume will probably become limiting before the reduction in oxygen transfer. A possible cause of inadequate oxygen transfer in a biofilter is insufficient ventilation. Corrective measures include increasing the size or number of ventilation ports, and providing forced draft ventilation (see Section 4.3.3).

Oxygen requirements in the aeration basin are dependent on the BOD_5 removal in the biofilter as well as the desired F/M loading to the basin. To allow flexibility in plant operation, it is recommended that a value of 0.8 kg O_2/kg $TBOD_5$ be utilized as the basis for sizing aeration equipment for ABF systems (20).

Facility modifications that improve oxygen transfer include:

- replacing coarse bubble diffusers with fine pore diffusers
- replacing surface mechanical aerators with fine pore diffusers
- supplementing surface mechanical aerators with diffused air or induced draft aerators
- increasing blower capacity by replacing or supplementing the existing blower(s)

Considerations for these modifications are presented in Section 4.4.5.

4.3.11 Inadequate Return/Waste Sludge Capability for ABF System

It has not been established that strict control of return flows is necessary to optimize the performance of an ABF facility. Consistent poor sludge settling characteristics are generally maintained because of the positive effects that the discrete, fixed-film sludge has on overall sludge settleability (21). Therefore, the need for close control of the return sludge flow to achieve desired performance is minimized.

Since the aeration basin is generally responsible for removing the majority of the BOD_5, adequate control of sludge age and sludge wasting is necessary. As such, modifications to provide sufficient wasting capacity or flexibility are warranted. For information on modifications to increase waste sludge flexibility, refer to Section 4.4.

4.3.12 Inadequate Hydraulic Wetting for ABF

In ABF treatment plants that have inadequate hydraulic wetting capability, solids accumulation in the biofilter can occur, resulting in decreased BOD_5 removal efficiency and sudden sloughing of solids (see Section 4.3.3).

4.3.13 Undersized Clarifier

"Undersized Clarifier" represents a capacity limitation when an excessive surface overflow rate results in the loss of SS in the effluent. Secondary clarifiers utilized in fixed-film systems are usually designed for surface overflow rates of 40-48 $m^3/m^2/d$ (1,000-1,200 gpd/sq ft) at peak hydraulic flow rates. "Undersized Clarifier" can also be a limitation when shallow clarifier depth causes insufficient volume for solids separation, thickening, and storage. In the past, many fixed-film, secondary clarifiers were designed with side water depths of 2.4-3 m (8-10 ft). Recent designs have utilized depths of 3.7-4.9 m (12-16 ft). Some designs incorporating the TF/SC process utilize clarifiers with side water depths in the 6-6.6 m (18-20 ft) range and flocculating center wells (22). If an existing fixed-film facility is modified to include suspended growth process, an existing secondary clarifier may not be adequate because of the different sludge settling characteristics.

In some cases, the performance of an undersized clarifier can be improved through the addition of internal baffles or polymers/coagulants to the clarifier influent. The coagulants most commonly used in wastewater treatment include: lime, alum, ferric chloride, ferrous sulfate, ferric sulfate, and sodium aluminate (2). Typically, chemical addition is not considered a long-term solution because of increased O&M costs and sludge production that result from the practice.

4.3.13.1 Relocation of Recirculation Flows

Facilities that recirculate flow following a secondary clarifier can exert a significant hydraulic load on the clarifier. Studies have shown that comparable performance is achieved from trickling filter systems that recirculate flow before and after the secondary clarifier (2). Consequently, a modification to remove the recirculation flow from the secondary clarifier can be used to improve performance. To evaluate the potential improved performance, the recirculation flow can be stopped and resulting SS removal can be assessed.

4.3.13.2 Flow Equalization

The addition of flow equalization facilities to a treatment plant can improve performance of a secondary clarifier by allowing the unit to operate more consistently at the daily average flow rate. These facilities should always be added ahead of the biological reactor and not between the reactor and its clarifier. The pumping associated with equalization facilities will break apart biological floc and affect its capture in the clarifier. Information on flow equalization can be found in Section 4.2.

4.3.13.3 Additional Clarifier

In treatment plants experiencing high clarifier surface overflow rates, as in facilities that may be used for suspended growth systems, the construction of an additional clarifier should be considered. Flocculator clarifiers in conjunction with the TF/SC process have been successfully used in upgrading trickling filter facilities (see Section 4.3.1.3). Studies have shown that the flocculator clarifier is, within limits, insensitive to increases in overflow rate; consequently, they can achieve excellent SS removal (13). The average effluent TSS of the Còuer d'Alene, Idaho, trickling filter plant decreased from 25 mg/L to 16 mg/L when the original 2.1-m (7-ft) deep clarifier was replaced with a flocculator-clarifier (92).

Additional design information for flocculator-clarifiers can be found in Section 4.4.7.1, and general design information on clarifiers can be found in several sources (2,93).

4.3.14 Excessive Clarifier Hydraulic Currents

Excessive currents within the clarifier can contribute to loss of solids at the effluent weir. Currents exist in all secondary clarifiers but typically have more pronounced effects in suspended growth clarifiers than in fixed-film facility clarifiers, but are present nevertheless. These currents develop in clarifiers as the result of density and temperature differences between the influent wastewater and clarifier contents. A discussion on hydraulic currents can be found in Section 4.4.

4.4 Suspended Growth Treatment Processes

A large number of secondary treatment facilities utilize suspended growth processes for achieving effluent compliance. Processes within this category include conventional, complete mix, extended aeration, contact stabilization, step feed, pure oxygen, and oxidation ditch activated sludge systems. The common components for these processes include:

- return sludge equipment
- waste sludge equipment
- oxygen transfer equipment
- aeration basin(s)
- mixing equipment
- solids separation equipment

The ability to adjust the mass of organisms in a suspended growth facility, coupled with proper use of the other process variables, offers a significant resource in expanding the performance capability of this type of plant. For this reason, modifications to utilize this flexibility are warranted. Proper operation is needed to support suspended growth facility modifications.

Optimizing performance requires the development of good sludge characteristics. For a given system, four major controls are available: 1) sludge mass control, 2) return sludge control, 3) DO control, and 4) aeration basin configuration. This relationship is graphically shown in Figure 4-12. Although each of these controls is important and must meet certain minimum requirements, a priority in terms of impact on performance can be established. Sludge mass control, or the capacity to waste the desired sludge mass, has frequently been identified as a major performance limiting factor in suspended growth systems (23). Facility modifications to address this limitation offer significant potential for improved performance. Aeration basin configuration flexibility allows changes in operational modes to control the development of good sludge characteristics. Improving return sludge or DO control offers a lesser potential for improving plant performance.

Figure 4-12. Relationship of variables for optimizing suspended growth facility performance.

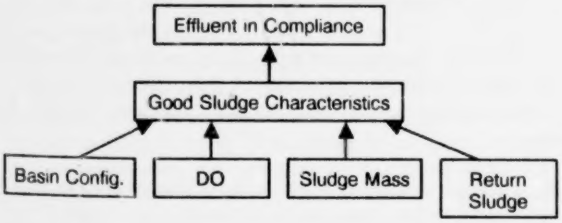


Table 4-6 summarizes design limitations/corrective modifications that are prioritized based on their potential for achieving improved performance. Modifications with proven reliability and those that are less construction intensive appear at the beginning of the listing.

Table 4-6. Suspended Growth Design Limitations and Potential Modifications

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4.4.1 Inadequate Waste Sludge Flexibility/Capacity

The ability to control the sludge mass is necessary to maintain good sludge characteristics and, in turn, desired effluent quality. Sludge mass is controlled by the amount of sludge wasted from the system. A systematic sludge wasting schedule, which is supported by process control testing and data collection and analysis, is the basis for providing this control. The operation of the suspended growth process should not have to be modified because of limitations of the sludge wasting, treatment, and disposal facilities.

Once sludge is removed, it is typically directed to some type of sludge treatment facility, such as thickening, digestion, and dewatering. Inadequately sized sludge treatment facilities necessarily limit the ability to waste sludge from a suspended growth system; however, they do affect sludge handling and stabilization capability. In a similar manner, limited sludge disposal alternatives can have a negative impact on the capacity of sludge treatment facilities, which in turn can affect sludge wasting from the suspended growth system.

The following sections discuss alternatives for improving the waste sludge flexibility/capacity.

4.4.1.1 Sludge Disposal/Utilization Management

Ultimately, waste sludge must be removed from the plant and disposed in an acceptable manner, such as landfilling or composting. Application of sludge on agricultural land is currently a common method of sludge utilization; however, this method by itself frequently places significant limitations on treatment facilities. Inclement weather conditions, high ground water, odor generation, and controlled access to farmland are limitations that affect this disposal method. A good sludge management program requires the availability of several disposal or utilization methods at a treatment plant. For example, a land application program could be augmented with lagoons for long-term storage and composting as an alternative utilization method. This type of flexibility assures the removal of sludge from treatment facilities, which, in turn, assures unlimited wasting capability from the suspended growth process. Further considerations for sludge disposal and utilization are presented in Section 4.7.

4.4.1.2 Sludge Treatment Facilities

Sludge treatment and storage facilities should be sized based on actual sludge production, including consideration for periods of peak production that occur due to changes in loading, temperature, and operational mode. Information on estimating sludge production can be found in Section 3.4. Information on modifications to sludge treatment facilities is presented in Section 4.7.

4.4.1.3 Separate Waste Sludge Pumps

Separate waste and return sludge pumps provide the flexibility to optimize each function. In most plants that use a common pump for these functions, the design of this equipment was based on the return sludge requirements. Typically, their sludge is wasted from the return sludge flow stream, which can overload subsequent sludge handling facilities. Selection of a separate waste sludge pump should include the following considerations:

- In small- to medium-sized plants, a positive displacement pump, such as progressive cavity or rotary lobe type, is typically the most appropriate pump for these conditions. For larger plants, centrifugal pumps are usually more cost effective.

- Include variable speed drives, time clocks, or a combination of both to provide needed flexibility.

- Include a flow measurement device to optimize the pumping rate (see Section 4.4.1.6).

4.4.1.4. Sludge Wasting to Thickener

Thickening equipment, such as dissolved air flotation, can be used to increase the solids concentration of waste sludge from less than 1 percent (weight basis) to 1.5-3.0 percent. For short periods of time, secondary waste sludge can be directed to primary clarifiers for thickening with primary sludge. This practice, over a long period of time, can dramatically decrease the waste sludge concentration from the primary clarifier. Additional information on sludge thickening can be found in Section 4.7.

4.4.1.5 Separate Waste Sludge Hopper in Clarifier

The use of a designated hopper for the withdrawal of waste sludge from clarifiers can be used to maximize sludge concentration, thus minimizing sludge volumes to the sludge treatment process. Modifying an existing clarifier to include a separate waste sludge hopper is, in most cases, not practical because of the demolition and construction requirements. However, if the plant modification includes a new clarifier, this option should be considered. A designated waste sludge hopper can also be incorporated into clarifiers that utilize vacuum sludge pickup for returning sludge.

4.4.1.6 Flow Measurement

Waste sludge mass is determined from the concentration and volume of wasted sludge. Flow measurement equipment is desired to determine volume; however, where equipment is not present, the waste sludge volume must be estimated.

Pump calibration can be used to estimate waste sludge flow rate. For a centrifugal pump, the flow rate is dependent on the pump speed and head. A pump curve which describes this relationship can be developed under field conditions by measuring a timed volume displacement in a basin versus the pumping condition (i.e., rpm, head). Once this curve is established, it can be used to estimate the flow rate for various speed settings. This method sometimes can be unreliable because of the effects of variable waste sludge concentrations and plugging on the flow rate.

For positive displacement pumps, the flow rate can be estimated from the pump speed (i.e., rpm) since capacity is essentially constant over the typical head conditions. The speed of the pump can be determined by attachment of a tachometer.

The recommended approach for determining sludge flow rates is through the use of appropriate flow measurement devices. Primary devices such as flumes and weirs are recommended because of their ease of calibration; installation of such devices in existing plants usually requires some ingenuity. Consideration can also be given to the installation of secondary devices (e.g., magnetic meters and doppler meters) if there is some method available for checking their accuracy. A common method of checking the accuracy of a flow meter is by pumping the flow to a basin with a known volume.

4.4.2 Inadequate Process Flexibility

The lack of flexibility in a suspended growth process typically limits the plant's capability since most POTWs are required to operate under a variety of conditions. These conditions can include variable hydraulic loadings caused by infiltration/inflow, seasonal contributors and plant start-up, and variable organic loading resulting from industrial sources and plant start-up. Good plant performance under all of these conditions sometimes can require different aeration basin configurations.

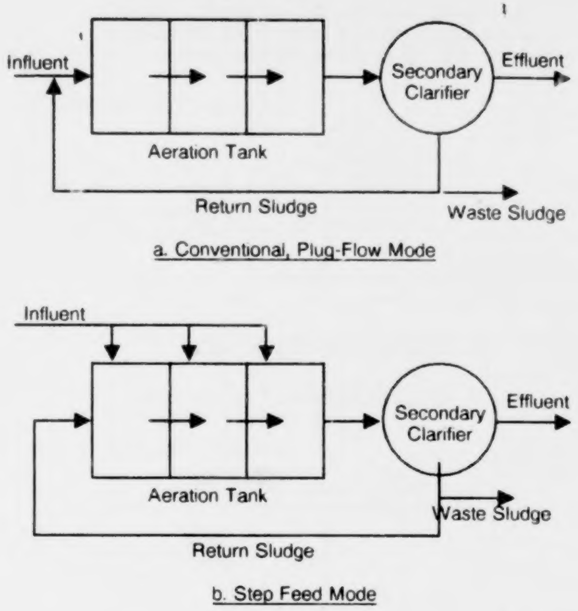
Existing suspended growth plants sometimes can be modified to operate under various conditions without extensive modifications and capital cost. In this section, methods of achieving process flexibility are presented together with their associated advantages and disadvantages. The complete mix operational mode is commonly utilized at larger suspended growth facilities; however, it is one of the most limited modes in terms of available detention time and sludge mass distribution capability. Possible alternatives for adding flexibility to a complete mix system are discussed in Section 4.4.2.3.

The development of filamentous sludge in a suspended growth system frequently requires corrective actions that also depend on process flexibility. Additional aeration capacity or changes in basin configuration are types of flexibility often needed. Because of the time required to make these types of changes, rapid methods of eliminating sludge bulking symptoms, such as chlorination of the sludge mass, may be necessary (88).

4.4.2.1 Step Feed

The impacts of flow and load variations can often be addressed by providing the plant with the flexibility to operate in the step feed mode. Flow schematics for the conventional plug flow and step feed activated sludge processes are presented in Figure 4-13. Step feed differs from the conventional configuration in that wastewater is fed in increments at several points along the length of the basin. In both schematics, return activated sludge enters the aeration basin at the head end of the process.

Figure 4-13. Flow schematics of conventional and step feed activated sludge processes.



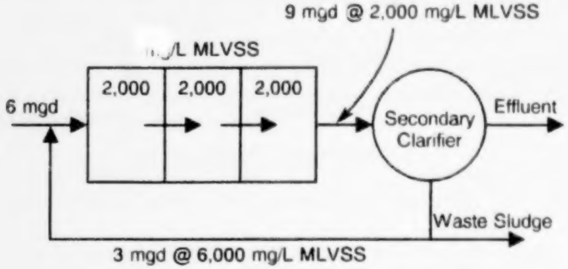
The step feed process can handle organic shock loads better than the conventional plug flow process. At an equal solids load to the secondary clarifier, the step feed process has a higher solids inventory under aeration than the plug flow process, thereby reducing the overall food-to-microorganism (F/M) loading. Additionally, the organic load and, therefore, aeration requirements, are more evenly distributed and locally high F/M loadings are avoided.

These features are illustrated in Figure 4-14. Each process receives an equal organic load [i.e., 11,350 kg (25,020 lb) $TBOD_5/d$] and the secondary clarifiers receive equal solids loads. There is a significant difference in the F/M loadings. The conventional plug flow process (Figure 4-14a) has an overall F/M loading of 1.0 kg $TBOD_5$/kg MLVSS/d, with a loading of 3.0 in the first basin. The step feed process (Figure 4-14b) has an overall F/M loading of 0.73; and no individual basin has an F/M loading greater than 1.0. Thus, the treatment plant operating in the step feed mode is less susceptible to process upset due to organic shock loads.

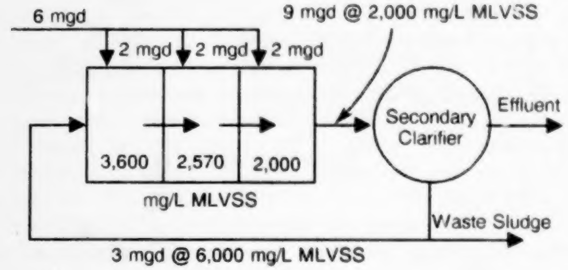
Operating in the step feed mode also provides more capability for handling hydraulic surges. Figure 4-15 is a simplified presentation of a process control change that can be made prior to a peak flow event to shelter solids from washout. As shown, the first feed inlet is valved off to create a sludge reaeration zone in the first basin. In effect, this shelters some of the solids from the mainstream of flow. The effect of this change is highly dependent on sludge settling characteristics

Figure 4-14. Advantages of the step feed process in treating organic shock loads.

Total Volume Under Aeration = 1.5 million gallons
Volume of Each Aeration Basin = 500,000 gallons
Influent = 6 mgd @ 500 mg/L BOD_5

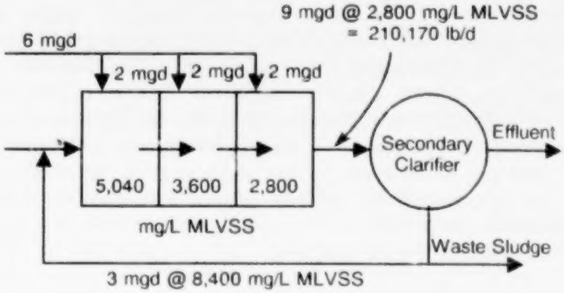

9 mgd @ 2,000 mg/L MLVSS
mg/L MLVSS
2,000
2,000
2,000
6 mgd
Secondary Clarifier
Effluent
Waste Sludge
3 mgd @ 6,000 mg/L MLVSS

a. Conventional, Plug-Flow Mode

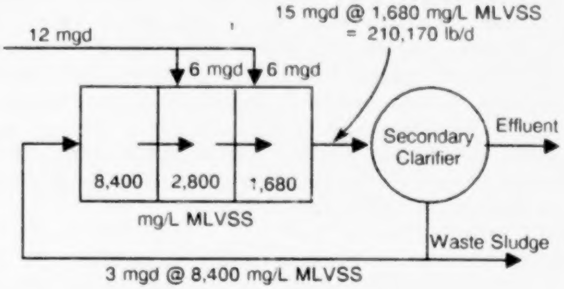

6 mgd
9 mgd @ 2,000 mg/L MLVSS
2 mgd
2 mgd
2 mgd
Secondary Clarifier
Effluent
3,600
2,570
2,000
mg/L MLVSS
Waste Sludge
3 mgd @ 6,000 mg/L MLVSS

b. Step Feed Mode

Figure 4-15. Managing hydraulic shock loads with the step feed process.


9 mgd @ 2,800 mg/L MLVSS
= 210,170 lb/d
6 mgd
2 mgd
2 mgd
2 mgd
Secondary Clarifier
Effluent
5,040
3,600
2,800
mg/L MLVSS
Waste Sludge
3 mgd @ 8,400 mg/L MLVSS

a. Before Hydraulic Surge


15 mgd @ 1,680 mg/L MLVSS
= 210,170 lb/d
12 mgd
6 mgd
6 mgd
Secondary Clarifier
Effluent
8,400
2,800
1,680
mg/L MLVSS
Waste Sludge
3 mgd @ 8,400 mg/L MLVSS

b. During Hydraulic Surge

and the duration of the hydraulic surge. Some decrease in BOD_5 and TSS removal should be anticipated under these conditions; however, performance should be considerably better than under the plug flow mode. Sludge wasting and return rates may need to be adjusted if the peak flow event lasts over several days. After the peak flows have passed, the process can be returned to the original step loading configuration.

The step feed process also can be used to reduce the solids loading rate to the secondary clarifiers. Improved clarifier effluent quality often results from reduced solids loading, especially if the solids settle poorly. Figure 4-16 illustrates two situations where clarifier solids loading rates are decreased while keeping the total inventory of solids under aeration at a constant level. This is accomplished by valving off feed inlets and creating sludge reaeration zones, which leads to a redistribution of the aeration basin solids. It may be necessary to temporarily adjust return and waste sludge rates to achieve the desired redistribution. A more complete description of the use of step feed to lower solids loading rates can be found in other sources (24, 109).

Modification of a conventional plug flow aeration tank to step feed generally requires dividing the aeration basins into separate compartments and changing the piping system so that wastewater can be fed in increments at any of several different points along the aeration basin. Ideally, flow measurement should be included for the flow entering each compartment. If the flow stream to each compartment can be seen by the plant operator, visual balance may be satisfactory and flow measurement equipment can be avoided. The aeration basin can be compartmentalized by adding either "curtain" walls or simple plywood partitions. The addition of load-bearing walls is quite expensive, usually unnecessary, and should be avoided At POTWs where multiple basins already exist, it may be simply a matter of cutting holes in the common walls to allow step loading flexibility. In most cases, the conversion will not require modifications to the aeration system unless tapered aeration is used. Typically, modifications to provide step feed capability are relatively inexpensive and can be carried out by the plant staff or local contractors. Any modifications that are made should maintain the capability of operating in the plug flow mode.

Case History: Keokuk, Iowa Wastewater Treatment Plant

A schematic of the Keokuk wastewater treatment plant is shown in Figure 4-17. The plant was experiencing performance problems due to a high strength, highly

Figure 4-16. Use of step feed to reduce solids loading to the secondary clarifier.

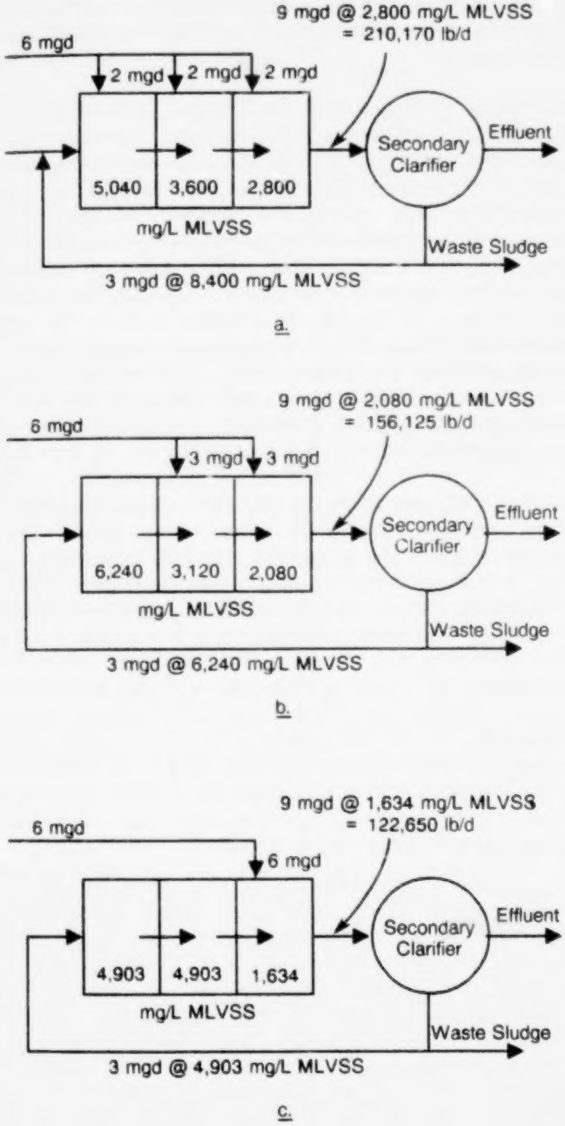
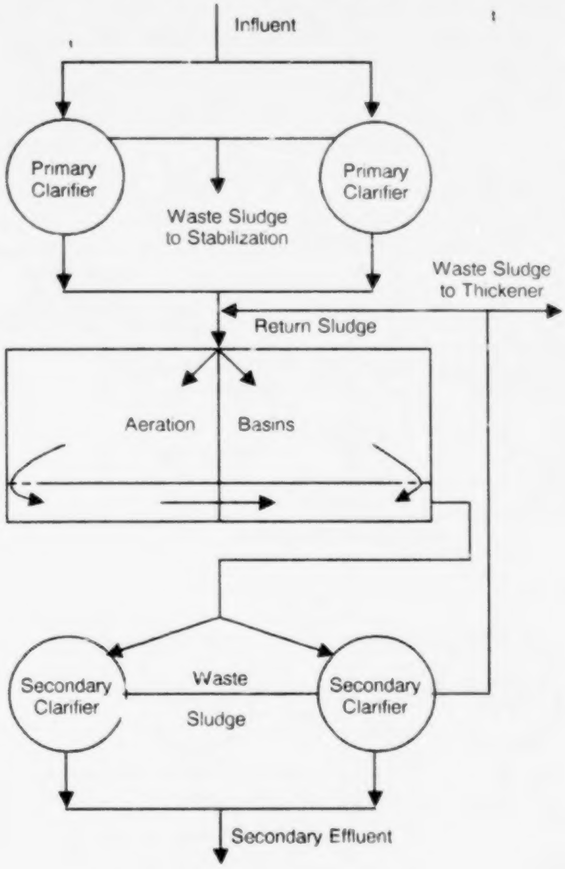

9 mgd @ 2,800 mg/L MLVSS
= 210,170 lb/d
6 mgd
2 mgd
2 mgd
2 mgd
5,040
3,600
2,800
Secondary Clarifier
Effluent
mg/L MLVSS
Waste Sludge
3 mgd @ 8,400 mg/L MLVSS
a.
9 mgd @ 2,080 mg/L MLVSS
= 156,125 lb/d
6 mgd
3 mgd
3 mgd
6,240
3,120
2,080
Secondary Clarifier
Effluent
mg/L MLVSS
Waste Sludge
3 mgd @ 6,240 mg/L MLVSS
b.
9 mgd @ 1,634 mg/L MLVSS
= 122,650 lb/d
6 mgd
6 mgd
4,903
4,903
1,634
Secondary Clarifier
Effluent
mg/L MLVSS
Waste Sludge
3 mgd @ 4,903 mg/L MLVSS
c.

Figure 4-17. Organic loading configuration for Keokuk, Iowa Wastewater Treatment Plant.


Influent
Primary Clarifier
Primary Clarifier
Waste Sludge to Stabilization
Waste Sludge to Thickener
Return Sludge
Aeration
Basins
Secondary Clarifier
Waste Sludge
Secondary Clarifier
Secondary Effluent

variable industrial load and high flows due to inflow during rainfall events. In addition, the industrial waste encouraged a slow settling bulky sludge. During this time period the average flow to the plant was 197 L/s (4.5 mgd), and the aeration basin detention time was about 29 hours. Numerous attempts to increase sludge mass in the aeration basins were initiated while the basins were operated, as indicated in Figure 4-17. As the mass increased, solids loss would occur in the final clarifiers.

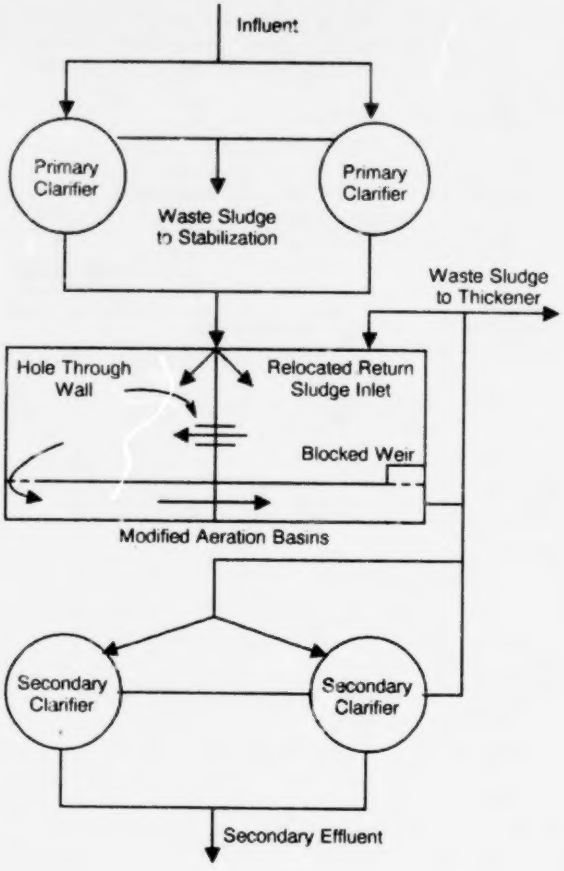
The plant staff modified the process by cutting a hole in the wall between the two aeration basins and modifying the return sludge piping as shown in Figure 4-18. With this modification, the plant was able to operate either in the step feed or contact stabilization mode, and the mass in the system was increased dramatically. Despite the variable industrial loads, the higher mass resulted in more stable operation and allowed a method of protecting solids loss during storm events.

Prior to the modification, the plant exceeded the discharge requirements every month. After the modification, the plant cycled into and out of compliance on approximately a quarterly basis. The key change, as the result of the modification, was the fact that the microbiological population went from high numbers of filamentous organisms to a more mixed population, including some free swimming organisms. Routine compliance was not achieved until one of the major industrial contributors built their own facility and went off line from the municipal system.

4.4.2.2 Contact Stabilization

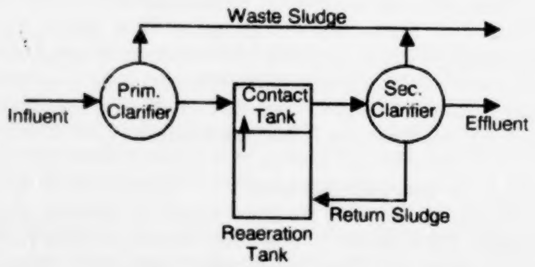
Modifying an existing aeration basin to operate in the contact stabilization mode can assist in alleviating performance problems associated with high flows. A

Figure 4-18. Modified loading configuration for Keokuk, Iowa Wastewater Treatment Plant.



flow schematic of a typical contact stabilization process is shown in Figure 4-19. The process involves a short term aeration phase (0.5-1.0 hr) in which substrate is rapidly transferred from the wastewater to the biological sludge and a long term sludge reaeration phase (3-6 hr) in which the absorbed substrate is metabolized. It is important to keep the detention time in the contact phase short to ensure process stability. Longer detention times result in poor sludge settling characteristics and undesirable performance.

Figure 4-19. Contact stabilization mode of the activated sludge process.



In comparing Figure 4-19 with Figure 4-16c, it is seen that the flow distribution for contact stabilization is essentially the same as that for step feed when only the last basin is fed. Modifications needed for step loading can also provide the capability to operate in the contact stabilization mode. However, the biological sludge found in an efficiently operating contact stabilization process is different from that of a step feed process in terms of oxygen uptake rate and biokinetics. These different properties require time to develop and stabilize and, therefore, it is recommended that changes between the plug flow/step loading mode and contact stabilization mode not be performed on a frequent basis.

Contact stabilization plants are the least susceptible to solids loss during hydraulic surge events. Solids in the reaeration basin are protected from the mainstream of flow, thereby minimizing solids washout. The effects of hydraulic surges can be minimized even further by building up the solids inventory in the reaeration basin prior to increases in flow. This can be done by decreasing the return sludge rate, thereby returning a thicker sludge to the reaeration basin. Some degradation in BOD_5 removal will probably occur during this time because of low MLSS concentration in the contact basin; however, once the peak flow event has passed, this concentration can be quickly increased to improve BOD_5 removal.

The contact stabilization mode may also be able to handle organic shock loads better than a conventional process. Contact stabilization plants are best suited for treating wastewaters with a high percentage of colloidal (non-soluble) organics, as is common for most domestic wastes. If the shock load consists mostly of colloidal organics, the contact stabilization process is capable of providing effective treatment without process upset. However, if the shock load consists mostly of soluble matter, organics can "bleed through" a contact stabilization process.

The total basin volume required for contact stabilization is less than that required for conventional systems. Therefore, conversion of a plug flow system to contact stabilization can often be accomplished by dividing the existing aeration basin into two separate compartments with a division wall. A load-bearing division wall allows for draining of each basin separately for cleaning and maintenance. A curtain wall is more economical to install but does not allow for separate draining of each basin. The contact basin should be sized to allow for 0.5-1.0 hr detention time at daily average flow rates, with the remainder of the basin being used as the reaeration tank. To be effective, the volume of the reaeration basin should be approximately three to four times greater than the volume of the contact basin. Piping and valves must be installed to route return activated sludge to the reaeration basin and both wastewater and reaerated sludge to the contact basin.

Modifications to the air distribution system may not be required. It is suggested that actual operating experience be used to indicate if the contact basin is oxygen limited before modifications are made. New construction of contact stabilization plants calls for about three to four times more oxygen per unit of basin volume for the contact basin than for the reaeration basin.

Since contact basins are typically designed for 0.5-1.0 hr detention time, they are relatively small and short-circuiting can occur. When modifying an existing basin to include contact stabilization capability, it is important to locate the influent and effluent piping at opposite locations in the contact tank. In some cases, baffling within the contact tank will be required.

4.4.2.3 Plug Flow

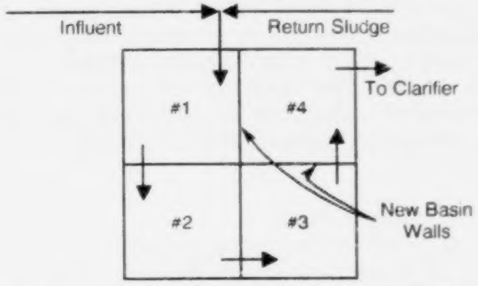
Plug flow systems can often be used to develop a stable sludge or to optimize treatment once a stable sludge is achieved. Plug flow capability can be provided by modifying basins to obtain high length-to-width ratios or by subdividing a basin into compartments. The following discussion presents some considerations for achieving plug flow capability in various types of suspended growth plants.

If influent organic loading is in a soluble form, a plug flow system will provide better treatment than a contact stabilization system. Typically, a contact stabilization plant can be easily modified to incorporate the plug flow mode by the addition of piping or a channel to direct the wastewater influent to the head of the reaeration basin. Flexibility should be included to provide step feed capability since the additional expense would be minimal.

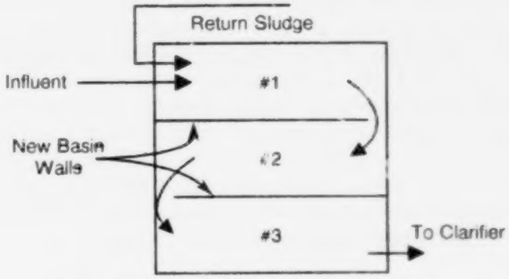
Complete mix activated sludge plants are limited in flexibility. Flexibility could be added by dividing the aeration basin into smaller compartments and modifying the influent, effluent, and return sludge piping or channels. If several complete mix basins are available, the piping could be modified to operate the basins in series. When a single basin is available, a compromise is typically made in the number of compartments provided because of capital cost and the decreasing improvement in performance with the increasing number of compartments. A typical modification would consist of dividing a complete mix basin into four compartments of equal size. Another alternative would include the addition of parallel walls in the basin to form a serpentine flow pattern. These configurations are shown in Figure 4-20.

A complete mix modification will also be dependent on the type of aeration system being utilized. When a basin is divided into smaller compartments, it is important that adequate aeration is provided in each compartment. This is especially true with the plug flow configuration since the higher organic loading in the beginning of the basin will result in a higher oxygen demand. If a mechanical aeration system is utilized, conversion to a plug flow system may not be economical because of aeration modifications that may be required. In these situations, it may be more economical to install additional aerator volume.

Figure 4-20. Conversion of complete mix to plug flow.



a. Conversion by segmenting basin into compartments



b. Conversion by addition of baffle walls

4.4.2.4 Chemical Addition

Chemical addition can be utilized to improve a sludge bulking problem caused by filamentous organisms by enhancing the sludge settling rate or selectively killing the organisms. Synthetic polymers or inorganic coagulants can be used to enhance settling characteristics. A wide variation in polymer type and dosage have been reported; consequently, jar testing is recommended. In general, the addition of polymer for bulking control is more expensive than selective chlorination of the sludge mass (88). Inorganic coagulants, such as alum and ferric chloride, can also be used to enhance sludge settling; however, these chemicals produce voluminous precipitates which increase the solids loading to subsequent sludge handling facilities. Information on the design of chemical feed facilities can be found in Reference 89.

Both chlorine and hydrogen peroxide have been used successfully in the selective destruction of filamentous organisms. A variety of dosing points have been used, including: 1) the aeration basin, 2) the flow channel between the aeration basin and clarifier, and 3) the return sludge stream. The most common dosing point is the return sludge stream. If a long aeration basin detention time exists, it is usually more advantageous to dose directly into this unit. Design and operational considerations for chlorine and hydrogen peroxide addition are presented in Reference 88.

Chlorine addition has been successfully used at the Missoula, Montana wastewater treatment plant. Chlorine is added to the return sludge stream and to the aeration basin. When filamentous sludge characteristics develop, a chlorine dosage of 6-8 kg Cl_2/1,000 kg VSS is split equally between these two dose points. This method of dosing has been consistently effective in achieving a positive improvement in sludge settling characteristics within one day (98).

4.4.2.5 Selector Basin

Various types of filamentous organisms have been found in suspended growth systems. The use of a high to low F/M gradient has shown success in controlling the low-F/M type filamentous bulking. This approach can be produced in continuous flow systems by utilizing selector or plug flow reactors. Strategies include operation of the selector or initial compartment of a plug flow reactor in a fully aerobic (i.e., $DO > 2$ mg/L) environment or in an oxygen deficient (i.e., $DO \leq 0.2$ mg/L) environment, both operating at high F/M loadings (i.e., ≥ 3 g BOD_5 applied/g MLSS/d) (26). Under both conditions, the high F/M loading encourages the growth of zoogleal colonies over the growth of filamentous organisms.

Various approaches have been proposed for selecting the size of aerobic selectors (99-101). The mechanisms by which selectors function to prevent filamentous orgamism growth and bulking at low F/M conditions have been investigated (25). This investigation showed that aerobic selector systems were only successful in controlling bulking over a narrow range of selector sizes. For the wastewater and activated sludge studied, the successful selector detention time and selector F/M ranges were 12-18 minutes and 20-30 g COD/g MLVSS/d, respectively.

An existing suspended growth system could be modified to include an aerobic selector by partitioning part of the aeration basin or by the addition of separate comaprtment (s). It has been suggested that selector systems can be designed on the basis of experiments using fill-and-draw systems (25). It is recommended that several compartments and bypass capability be included in the selector design to allow flexibility in loading and detention time. An example layout of a complete mix suspended growth process modified to include selector basins is shown in Figure 4-21.

Experience with the oxygen deficient selector indicates that an OUR:DO greater than 250:1 should be maintained to assure anaerobic conditions (i.e., zero DO and NO_3-N) in the inner cell structure. Factors such as mixing, floc size distribution, and diffusional resistance will influence this relationship. The selector should comprise at least two compartments, and the volume of the first compartment should maintain an F/M loading of at least 2.3 g BOD_5/g MLSS/d. The first compartment will typically comprise 2-5 percent of the total biological basin volume. Initial low DO zones can comprise 10-40 percent of the total biological basin volume depending on the design objectives (26,102). This strategy is also utilized in various biological phosphorus removal processes (27).

4.4.3 Undersized Clarifier

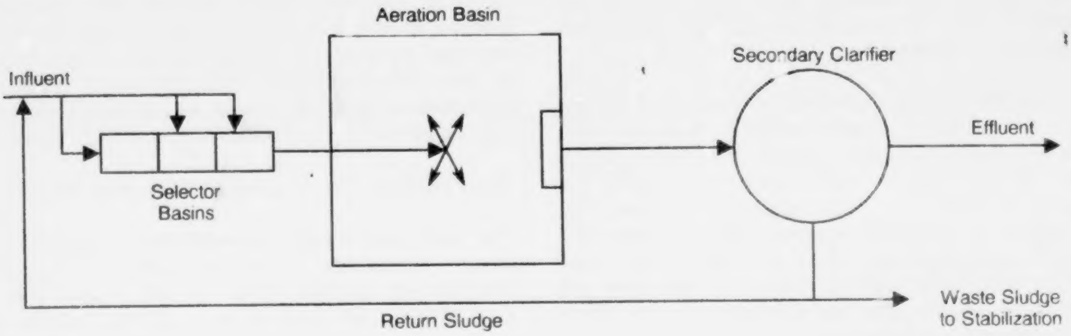
A common misconception associated with the performance of clarifiers in suspended growth systems is that solids loss is the result of a clarifier failure, when, in fact, it is often due to poor sludge settling characteristics. Sludge settling characteristics are established by the system environment (i.e., aeration basin and clarifier) and the process control parameters (i.e., mass, DO, return rate, and basin configuration). It is important that process control be evaluated thoroughly before any decision is made to correct a clarifier design deficiency (i.e., additional capacity can be achieved from an existing clarifier by changing to the step feed mode, as discussed in Section 4.4.2.1).

A clarifier limitation may exist if the following criteria are exceeded. Secondary clarifiers are usually designed for surface overflow rates of 16-32 $m^3/m^2/d$ (400-800 gpd/sq ft). Depth is also an important parameter that is necessary to provide solids separation, thickening, and storage. Storage is necessary because of changes in the solids distribution between the aeration basin and clarifier that occurs as a result of diurnal flow variations. A sidewater depth of 3.6-4.3 m (12-14 ft) is commonly used; however, some contemporary designers utilize clarifiers with sidewater depths in the 4.9-6.1 m (16-20 ft) range (45).

4.4.3.1 Flow Equalization

A common method used to reduce the effects of peak flows on clarifiers is flow equalization. Information on flow equalization is presented in Section 4.2.1.5. In some situations, sufficient flow equalization can be achieved by utilizing the available freeboard in the aeration tanks. This can be accomplished by: 1) increasing the hydraulic resistance of the outlet weir from the aeration basin with the corresponding increase in water depth, or by 2) pumping from the aeration basin to the clarifier. Additional information on

Figure 4-21. Selector basin modification.



these techniques can be found in other sources (86,87). Before this method of flow equalization is pursued, the effect of varying water depths on the existing aeration system must be evaluated.

4.4.3.2 Additional Clarifiers

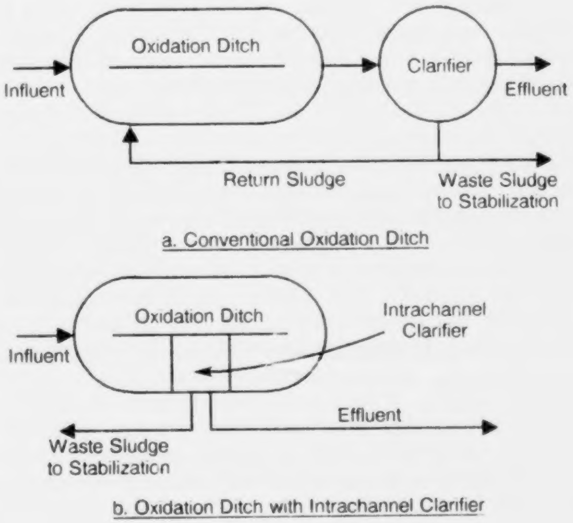
If existing clarifier overflow rates are high under average flow conditions, the construction of an additional clarifier may be warranted. Before adding clarifiers, however, investigate the effectiveness of internal clarifier baffles (see Section 4.7). An important consideration when adding new clarifiers, often of different size and capacity, is flow splitting. When flow splitting to multiple clarifiers is required, positive flow control can be accomplished by construction of a flow control structure with mechanically-adjusted control gates. A staff gauge located near the control gate, can be used to measure the flow rate to each clarifier. Information on the design of clarifiers can be found in other sources (2,93).

4.4.3.3 Intrachannel Clarifiers

A recent innovation involves the use of an intrachannel clarifier in the aeration channel (46). These devices allow solids/liquid separation within the aeration channel, thus eliminating the need for a separate clarifier, as shown in Figure 4-22. This alternative would be appropriate for an undersized secondary clarifier utilized in an oxidation ditch treatment facility. The volume reduction associated with this modification is typically not significant, since most oxidation ditches are designed with conservative detention times of 20 hr or greater.

Influent flow to an intrachannel clarifier is typically through the clarifier bottom; however, other designs direct the influent through the end or side. A quiescent zone is created by the walls of the clarifier structure, and the settled water is collected by either overflow or submerged weirs. The settled sludge exits the clarifier through a baffled bottom section and is carried away by the passing mixed liquor flow. Several manufacturers currently market intrachannel clarifiers. Information on the various designs is provided elsewhere (46).

Figure 4-22. Conventional vs. intrachannel oxidation ditch systems.



a. Conventional Oxidation Ditch

b. Oxidation Ditch with Intrachannel Clarifier

Intrachannel clarifier modifications provide options for the use of the abandoned secondary clarifier. The unit could be used in series with the intrachannel clarifier or it could be used as a thickener for waste sludge from the oxidation ditch. Since mixed liquor is normally wasted from facilities utilizing an intrachannel clarifier, availability of a thickener would benefit the other sludge handling facilities.

4.4.4 Undersized Aeration Basin

Aeration basins for suspended growth systems are sized based on hydraulic detention time and organic and volumetric loading rates. The aeration basin hydraulic detention time varies depending on the operational mode being. Detention times can vary from 2-4 hr for a complete mix process to 18 hr and greater for extended aeration processes. Organic loading (F/M) typically ranges from less than 0.10 kg BOD_5/kg MLSS/d for extended aeration processes to over 0.4 kg BOD_5/kg MLSS/d for complete mix processes. Volumetric loading rates vary from a low of

0.16-0.32 kg $TBOD_5/m^3/d$ (10-20 lb/d/1,000 cu ft) for extended aeration processes to a high of 0.8 kg $TBOD_5/m^3/d$ (50 lb/d/1,000 cu ft) or more for complete mix processes.

Operational alternatives should be examined before addressing aeration basin volume deficiencies. Additionally, load reduction should be investigated. Possible areas where load reduction could be achieved include: 1) side stream control, 2) pretreatment of industrial wastes, and 3) improved efficiency of preliminary and primary treatment processes. If it is determined that these solutions will not provide adequate performance, physical modifications will be necessary.

4.4.4.1 Flow Equalization

Flow equalization facilities can be effectively used to reduce hydraulic and organic loading. Specific information on the modification to include flow equalization is provided in Section 4.2.

4.4.4.2 Fixed Film/Suspended Growth Systems

A film system can be added to provide a partial reduction in the organic loading (i.e., roughing) before final treatment in a suspended growth system. This modification requires the use of primary treatment prior to the fixed film system. If a filter is used, pumping is usually required for loading and recirculation. Various types of fixed film/suspended growth combinations are available (30).

In the roughing filter/activated sludge (RF/AS) process, a trickling filter is added in series with a suspended growth system. A schematic view of the process is shown in Figure 4-23. In this roughing application, high organic and hydraulic loadings are utilized. Typical organic loading rates are 1.6-3.2 kg $BOD/m^3/d$ (100-200 lb/d/1,000 cu ft), and hydraulic loading rates are 20-120 $m^3/m^2/d$ (500 to 3,000 gpd/sq ft) (8).

The combination of the discrete biological solids from the roughing filter and the zoogleal mass from the suspended growth system results in a sludge with excellent settling characteristics (31). Typically, this process also requires less power consumption since part of the organic load is treated by less energy intensive trickling filters. The amount of power savings depends on the share of the organic load that is removed by the roughing filter, the required pumping head to the filter, the amount of recirculation around the filter, and the turndown capability of critical process equipment such as blowers.

The rotating biological contactor/activated sludge (RBC/AS) and biofilter/activated (BF/AS) sludge processes also can be considered for modifying an overloaded suspended growth system. If the RBC/AS process is being considered, BOD_5 loading to the first stage of the RBC facility should be evaluated (see Section 4.3.5). In a BF/AS system, the return sludge from the suspended growth system is returned ahead of the trickling filter. The following case history illustrates a situation where an activated sludge plant was expanded by conversion to a BF/AS facility.

Case History: City of Casper, Wyoming BF/AS Facility (32)

The Sam Hobbs regional wastewater treatment facility treats wastewater from the City of Casper and surrounding entities. Prior to expansion, the facility was utilizing an air-activated sludge system with a capacity of 263 L/s (6 mgd). In 1985 the facility's capacity was increased to 631 L/s (14.4 mgd) by conversion to a biofilter/activated sludge system. A schematic drawing of the modified plant is shown in Figure 4-24, and design criteria for the BF/AS system is shown in Table 4-7.

Primary effluent from four primary clarifiers flows by gravity to the biofilter pumping system. The primary effluent mixes with return activated sludge and a portion of the biofilter effluent to be recycled over the tower. The amount of biofilter effluent recycle is dependent on the difference between the pumping rate and the actual influent flow rate (primary effluent and RAS) to the pump wet well. The maximum biofilter effluent recycle is limited to 219 L/s (5 mgd). The combination primary effluent, RAS, and biofilter effluent (mixed liquor) is discharged through a rotary distributor at the top of the biofilter. The plastic media used in the biofilter consists of rectangular PVC modules that measure 0.6 m x 0.6 m x 1.2 m (2 ft x 2 ft x 4 ft). The remaining biofilter effluent flows by gravity to four aeration basins operated in parallel. Effluent from the aeration basins is split equally to four secondary clarifiers. An RAS pumping system returns sludge from the secondary clarifiers at a rate proportional to the plant influent flow. A separate waste activated sludge pumping system diverts a portion of the activated sludge to a dissolved air flotation thickening system.

The plant is required to meet secondary treatment requirements, and a seasonal ammonia nitrogen limit of 9-12 mg/L. Consistent effluent BOD_5 concentrations of 15-20 mg/L were achieved when operating at an MCRT in the aeration basin ranging from 1.5 to 12 days. Corresponding effluent TSS levels ranged from 10 to 15 mg/L. Complete nitrification was achieved with the system when the MCRT was maintained above 8 days. SVIs ranged from 50 to 180 mL/g. Following the introduction of a routine biofilter flushing procedure and a change in the RAS mixing location, the SVI remained below 100 mL/g at MCRT values ranging from 1 to 4 days. The total secondary treatment power requirements were 0.55 and 1.2 kWh/lb BOD_5 at MCRT values of 1.5 and 8 days, respectively.

Figure 4-23. Roughing filter/activated sludge.

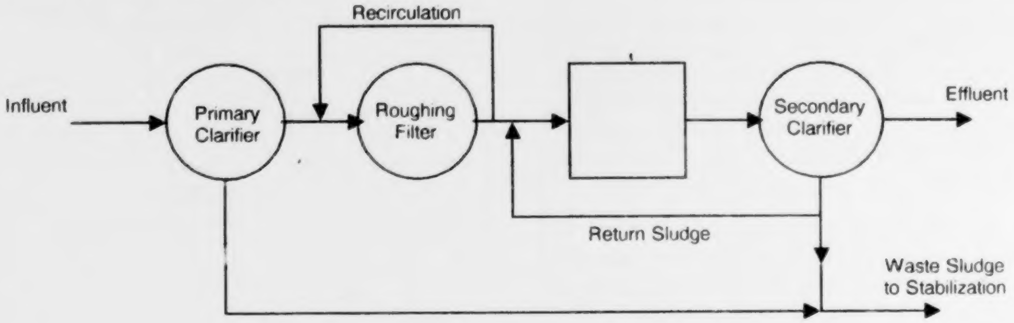

Recirculation
Influent
Primary Clarifier
Roughing Filter
Secondary Clarifier
Effluent
Return Sludge
Waste Sludge to Stabilization

Table 4-7. Design Criteria for Casper, WY BF/AS System

Parameter	Design Criteria
Design Capacity, m³/d	54,500
Biofilter	
Media Type	Stacked PVC Modules
Surface Area, m²/m³	96
Diameter, m	27.4
Depth, m	4.9
Total Media Volume, m³	2,860
Aeration Basin	
Volume (each), m³	1,892
Equipment	Surface Mechanical Aerators
No. Aerators per Basin	2 @ 30 kW

4.4.4.3 Additional Aeration Volume

Additional aeration volume can be accomplished through the construction of new tankage or often through the utilization of existing abandoned tankage. If this alternative is considered, the flexibility to allow use of suspended growth modes (e.g., step feed and contact stabilization) should be provided.

4.4.4.4 Biological Aerated Filter (BAF)

The BAF is a down flow, high rate, fixed film biological wastewater treatment system. A schematic flow diagram is shown in Figure 4-25. Primary effluent is directed downward through a packed bed of granular clay media. The media provides surface area for the growth of microorganisms and also removes SS via filtration. Air is introduced into the media bed to provide oxygen for biological growth. Effluent exits the reactor through a set of plastic nozzles located in an underdrain plate.

Excess biological solids and trapped SS are normally removed from the bed daily by backwashing the entire media with treated effluent. A blower is used to force air through the bottom of the bed during backwash to scour solids from the media. Spent backwash water is directed to the primary clarifier or plant headworks.

Figure 4-24. BF/AS system at Casper, Wyoming.

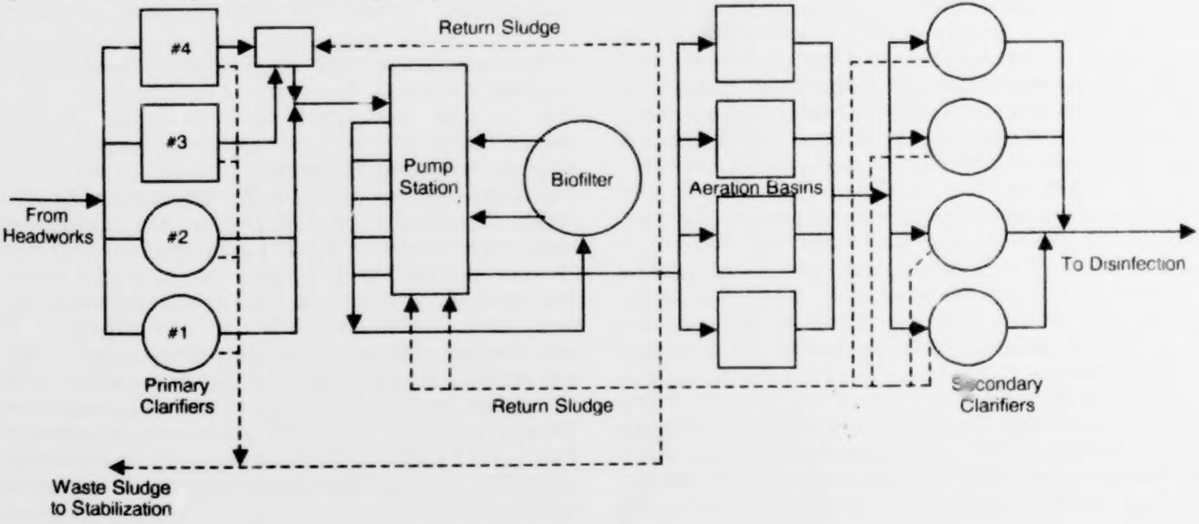
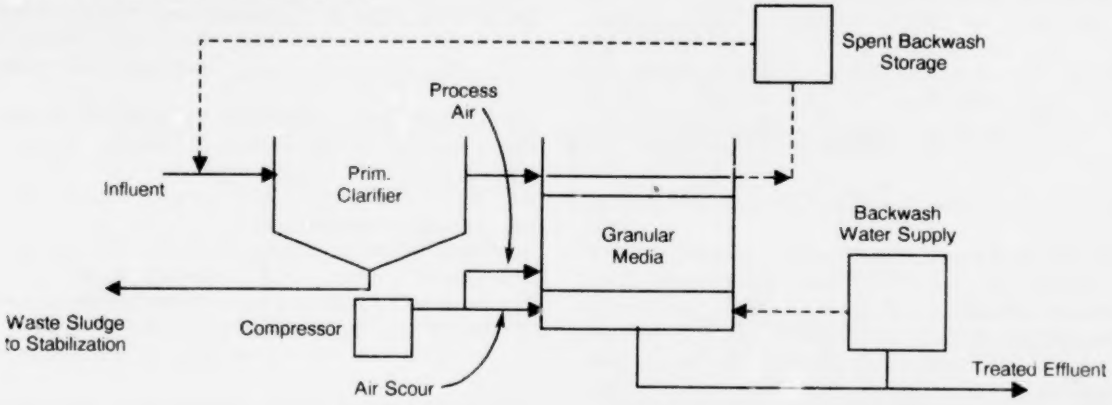

#4
#3
#2
#1
From Headworks
Primary Clarifiers
Return Sludge
Pump Station
Biofilter
Aeration Basins
Secondary Clarifiers
To Disinfection
Return Sludge
Waste Sludge to Stabilization

Figure 4-25. Biological Aerated Filter (BAF).



Plugging of the BAF reactor has been reported as a potential problem when treating high strength organic wastes. When clogging occurs in some part of the reactor - such as the granular media, air distribution piping, or water collection nozzles - backwashing sometimes is not effective in correcting this situation. It then becomes necessary to remove the media to perform cleaning and repairs. Success in eliminating reactor plugging by modifying the BAF understructure has been reported (105). The first modification included the replacement of the effluent collection nozzles with a layer of gravel which contained perforated pipe. The diameter of the perforations in the collection pipe were above 10 mm (0.4 in). The second modification involved the lowering of the aeration diffuser pipes into the gravel layer.

The modification of an existing suspended growth basin to a BAF is not compatible with the equipment provided by the system's manufacturer. Presently, modular plants complete with tankage, media, controls, and miscellaneous components are provided. Each module includes 46 m^2 (500 sq ft) of media surface. Use of a BAF system would probably be limited to treatment of in-plant or industrial sidestreams, treatment of part of the plant loading at a relatively constant rate (i.e., base load), or polishing of plant effluent to meet stringent treatment requirements.

The reported allowable soluble organic loading rate for a BAF unit is 1-1.4 kg/m^3/d (63-88 lb/d/1,000 cu ft) depending on the influent wastewater temperature (33). Reasonable run times between backwashes (i.e., 24 hr and greater) can be achieved at hydraulic loading rates of 0.68 L/m^2/s (1 gpm/sq ft) and less. With an effective media size of 4.4 mm, the amount of water used for backwashing is 7-10 percent of the influent flow. The system appears to have a higher solids yield and lower oxygen requirement than conventional activated sludge because of limited degradation of the SS that are removed by the media.

Since the BAF process is relatively unproven technology, a pilot study is recommended to establish site-specific design criteria.

Advantages of the process are summarized below:

- The need for a secondary clarifier is eliminated.
- Nitrification can be achieved at lower loading rates.
- The process is marketed in modular units that facilitates staged construction.
- Space requirements are significantly less than for a suspended growth system.

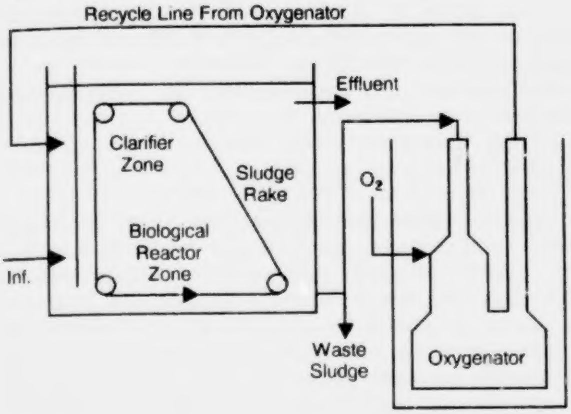
Limitations are:

- A primary clarifier is required.
- Modifying an existing suspended growth basin is limited since the process is marketed as a stand-alone unit.
- Process performance is affected by peak loading rates.

4.4.4.5 Two-Zone Process

The Two-Zone process was developed by Canadian Liquid Air, Ltd. as an alternative to conventional wastewater treatment systems. As shown in Figure 4-26, the process is essentially an activated sludge process that combines the aeration basin and secondary clarifier functions into a single tank. An external oxygenation device is used to super-saturate the sludge recycle stream, which is returned to the reactor to provide all of the oxygen requirements of the process. The Two-Zone process is designed so that it can be retrofitted into an existing aeration basin or clarifier, provided that the tankage is rectangular or square shaped.

Figure 4-26. **Flow diagram of the Two-Zone System.**



To establish the capabilities of the Two-Zone process to treat municipal wastewater in a retrofit situation, Canadian Liquid Air, Ltd. and the U.S. EPA jointly conducted a 22-L/s (0.5-mgd) demonstration project at Norristown, Pennsylvania (34). The study found that the process utilizes tank volume more efficiently than conventional activated sludge processes. The Two-Zone system was capable of achieving 82-87 percent TBOD removal and 85-93 percent TSS removal at F/M loadings of 0.33-0.95 kg TBOD/d/kg MLVSS, total tank detention times of 3.3-7.0 hr, and MCRTs of 1.2-3.7 days. These low MCRTs resulted in a relatively low process oxygen requirement (0.5 kg O_2/kg TBOD removed), and a high sludge production value (1.54 kg MLSS/kg TBOD removed).

If all existing aeration tanks and secondary clarifiers at a wastewater treatment facility are converted to the Two-Zone process, the treatment capacity of that facility will increase. If only the aeration basins are converted, it is likely that there will be no net gain in treatment capacity. Also, a higher demand will be placed on the capacity of sludge stabilization processes due to the high sludge production rate associated with the process. The Two-Zone process is not recommended for treatment facilities that must achieve nitrification or for those that have influent BOD_5 concentrations greater than 200 mg/L. In the demonstration project, the large quantity of oxygen that had to be provided for these conditions resulted in flotation of the biomass. The project report contains more detailed information (34).

4.4.4.6 Powdered Activated Carbon Treatment (PACT)

PACT is a waste treatment process marketed by Zimpro that is based on the combined use of powdered activated carbon and aerobic bacteria in the activated sludge process (35). In a typical system, carbon is added to the wastewater after the primary clarifier at a dosage rate based on the degree of treatment required. A small dose of liquid cationic polyelectrolyte is added prior to the final clarifier to improve effluent clarity. Also, teriary filtration is generally required to ensure the separation of PAC prior to discharge. A wet air oxidation process has generally been used to regenerate the spent carbon in municipal applications. The decant from the wet air oxidation unit can impose a high organic load on the plant because of the production of acetic acid in this unit operation.

Due to the adsorptive nature of the powdered activated carbon, the PACT process may be capable of removing many of the complex, high molecular weight organics that are difficult to biodegrade in conventional activated sludge processes. Included among these compounds are many organic toxins, priority pollutants, soluble dyes, and surfactants. As such, the PACT process has been applied at many industrial plants and at several municipal treatment facilities that receive significant industrial loads. Its applicability for municipal facilities should be determined on a case-by-case basis using pilot-scale studies. It is anticipated that the PACT process would not be cost effective for a municipal activated sludge system unless the reason for non-compliance is directly due to heavy industrial loads.

Operational problems associated with the regeneration system have been experienced at some municipal PACT facilities. At both the South Burlington, North Carolina and Bedford Heights, Ohio treatment plants, inability to separate the inorganic particulate matter from the regenerated carbon occured. As a result, the volatile solids content in the mixed liquor was as low as 34 percent, requiring excessively high MLSS concentrations to be maintained. At the Bedford Heights plant, the presence of heavy metals in the recycled ash contributed to permit violations associated with metals concentrations.

4.4.4.7 Porous Biomass Support Systems

Porous biomass support systems are a hybrid technology that combine many of the features of suspended growth and fixed-film processes. With these systems, thousands of small plastic foam pads are added to the mixed liquor in an aeration tank to serve as a support matrix for biological growth. The concept behind this approach is that the amount of biomass under aeration can be considerably increased, thereby lowering the F/M ratio and increasing the treatment capacity of the basin. Some systems, such as CAPTOR may not always require a secondary clarifier. Other systems such as LINPOR include a secondary clarifier and sludge recycle.

The Water Engineering Research Laboratory of the U.S. EPA conducted a 2-year pilot-plant evaluation of the CAPTOR process (36). The pilot plant was hydraulically loaded at a rate of 1.6-1.9 L/s (25-30 gpm).

The CAPTOR process utilizes polyurethane foam pads with dimensions of 1"x 1" x 1/2". Approximately 1,000 pads are added for every cubic foot of aeration tank volume (35,000 pads/m^3). A screen is inserted into the aeration tank's effluent discharge structure to retain pads in the tank. To waste excess sludge, pads are removed from the tank with air lift pumps and then conveyed to pressure rollers that squeeze the loosely entrapped and attached solids from the pads. The pilot-plant study identified several problem areas, including high concentrations of poorly set-tleable SS in the effluent, and poor process economics. Contrary to the manufacturer's claims, there was no evidence of improved oxygen transfer efficiency. Use of the pads did allow for operation with higher MLSS and waste sludge concentrations.

Porous biomass support technology is still in the developmental stages. Several full-scale LINPOR systems are in operation in Germany. Other processes, such as RING LACE, have been used in some facilities in Japan. At this point, however, the potential of porous biomass support processes for retrofit purposes is not well defined.

4.4.5 Inadequate Oxygen Transfer Equipment

Oxygen transfer can be achieved by utilizing surface mechanical aeration equipment, blowers in combination with diffused air equipment, or a combination of both. When inadequate oxygen is transferred, deterioration of effluent quality typically occurs because of insufficient oxygen to meet the biological oxygen demand and the endogenous oxygen demand of the biological mass. The development of filamentous organisms is also associated with low mixed liquor DO concentrations (37). This problem can indirectly result in effluent violations because of poor settling sludge characteristics.

Chapter 2 discusses a method of estimating the oxygen transfer capacity of an existing aeration system. Under most conditions, this estimation should provide sufficient information to determine whether inadequate oxygen transfer is occuring in an aeration basin. Following the modification or replacement of an aeration system, the actual oxygen transfer efficiency of the new system can be tested. The five methods currently used to measure oxygen transfer efficiency include: 1) steady-state analysis, 2) nonsteady-state analysis, 3) off-gas analysis, 4) inert gas technique, and 5) radioactive tracer technique. Information on these methods is available in other sources (82-84).

Methods of reducing the organic loading should be investigated before major modifications are made to an inadequate oxygen transfer system. Also, operational steps such as cleaning diffusers or removing rag accumulation on surface mechanical aerators should be pursued prior to modification alternatives.

4.4.5.1 Additional Blowers

Addition of more blowers may be appropriate to address an oxygen deficiency in a diffused aeration system. The installation of additional blowers to an existing system will increase the air velocity and associated headloss in the piping system. This additional headloss could overload the existing blowers.

Increased air flow per diffuser may reduce oxygen transfer efficiency. Oxygen transfer for dome and disc fine bubble diffusers configured in a grid pattern decreases significantly with increased air flow per diffuser. A smaller decrease is seen with flexible tube and porous plastic fine bubble diffusers. Typically, the oxygen transfer efficiency for coarse bubble diffusers is not affected by increased air flow per diffuser. Reference 30 includes specific information on air flow per diffuser and its effect on transfer efficiency for various types of diffusers.

4.4.5.2 Diffused Air System Upgrade

Oxygen transfer can be improved by replacing a mechanical system with a diffused air system or replacing a low efficiency diffused air system with a higher efficiency system. In some cases, replacing an existing mechanical aeration system with a fine bubble diffused aeration system can provide the needed additional oxygen transfer required. If sufficient water depth is available above the new diffusers [i.e., 3 m (10 ft) or greater], a fine bubble diffuser system will be more efficient than a mechanical aeration system. With this modification, consideration must be given to the space requirement for blowers and air piping, the need for soundproofing, the need for increased O&M, and special ventilation requirements for the blower room.

In many older suspended growth plants, coarse bubble aeration systems are utilized. Additional oxygen transfer can be achieved by replacing these systems with medium or fine bubble diffusers. In most cases, the existing blowers can be utilized since the higher efficiency diffusers require significantly less air volume.

The 3,945-L/s (90-mgd) Central Wastewater System Plant, a major wastewater treatment facility serving the Dallas, TX area, is a case where coarse bubble diffusers have been replaced with fine bubble diffusers (104). Effluent discharge limits are 10 mg/L BOD_5, 15 mg/L TSS, and 3-5 mg/L NH_3-N. Equipment age and other problems required the replacement of the existing "snap cap" coarse bubble diffusers, which had been operating for nine years. Over 50,000 ceramic disc fine bubble diffusers were installed in six 30 m x 90 m (100 ft x 300 ft) aeration tanks at a total project cost of $1.75 million, plus engineering fees. Construction was completed in June, 1988. Off-gas testing of the new aeration system showed an in-waste oxygen transfer of 16-17 percent. Following completion of the plant modification, the plant staff determined that only three of the existing four blowers would be needed to meet the secondary process air requirements. Projections show that the new fine bubble system will pay for itself in less than four years.

When designing fine bubble aeration systems, it is important to consider the potential for diffuser fouling. Air-side diffuser fouling is caused by dust, oil, rust, or scale in the air distribution system and from wastewater that enters the diffuser following an interruption in power. By exercising care during construction and by installing air filtration equipment, air-side fouling can be minimized. Liquid-side diffuser fouling is caused by oil and grease deposits, growth of a biofilm on the diffusers, and chemical precipitates.

A variety of cleaning techniques to address diffuser fouling are available. Some techniques require interruption of aeration system operation, while others do not. An additional distinction can be made between those cleaning techniques that require diffuser removal (*ex-situ*) and those that do not (*in-situ*).

Common *in-situ* cleaning methods are water hosing, steam cleaning, and acid cleaning, all of which are process interruptive. Gas cleaning is an *in-situ* method that is process noninterruptive. Both hosing and steam cleaning effectively remove loosely adherent liquid-side biological growths. The application of 14-percent HCl to each ceramic diffuser followed by hosing or steam cleaning can be effective in removing both organic and inorganic foulants. Gas cleaning involves the injection of an aggressive gas (e.g., HCl) into the air feeder lines. The gas is effective in removing most foulants with the exception of gelatinous slimes adhering to the liquid-side of the diffuser.

Refiring ceramic diffusers, an *ex-situ* technique, is the most expensive cleaning method. It involves removal of the diffusers and heating them in a kiln. The result is removal of most foulants both inside and outside the diffuser, and restoration to almost original condition. Additional information on diffuser cleaning is available in other sources (38,79). Given the increased O&M due to fouling of fine bubble diffusers, small treatment facilities may not find this conversion to be operationally attractive.

4.4.5.3 Mechanical Aerator Upgrade

The oxygen transfer capacity of some mechanical aeration systems can be increased through a combination of operational changes and equipment modification. Tests conducted at the Kitchener, Ontario, wastewater treatment plant demonstrated that the oxygen transfer capacity of existing surface mechanical aerators could be increased by approximately 40 percent by refurbishing the old aerator cones, increasing aerator submergence, and operating all aerators at a higher rotational speed (85). Oversubmergence should be avoided since this condition can result in decreased oxygen transfer.

Other considerations for providing supplemental aeration to an existing mechanical aeration system include the use of aspirating type aerators or diffused aeration around the periphery of the aeration tank. Aspirating aerators consist of a hollow tube with an electric motor on one end and a propeller at the other. The propeller draws air from the atmosphere at high velocity and injects it underwater where both velocity and propeller action create turbulence and diffuse the air into the water. These relatively low-efficiency aerators are portable and are typically mounted on floats where they can be positioned at various angles depending on basin depth and mixing and circulation requirements.

4.4.5.4 Roughing Filters

Oxygen deficiencies can be corrected by the addition of roughing filters. This modification is discussed in Section 4.4.3.2.

4.4.6 Inadequate Return Sludge Flexibility

Return sludge equipment is utilized to control the distribution of sludge between the aeration basin and the clarifier. Problems that can result in the violation of effluent standards are :

- unbalanced solids distribution and excessive hydraulic loading to the final clarifiers due to constant speed pumps
- variable flow rates due to plugging of control valves on the discharge side of constant speed pumps
- variable flow rates due to plugging and creep with the air flow control, on air lift pumps
- improper control adjustments due to lack of flow measurement

Typically, modifications required to correct a problem with a return sludge system are not extensive and can be completed by plant staff or local contractors.

4.4.6.1 Flow Recycle Around Pump

The use of a flow recycle system around a constant speed pump can be a simple method of achieving variable flow control for some return sludge applications. This concept is presented in Section 4.2.1.1.

4.4.6.2 Adjustable Speed Drives

The most effective method of providing a wide range of return sludge flow rates is by utilizing pumps with adjustable speed drives. Existing constant speed pumps can be retrofitted with equipment to achieve adjustable speed control, including:

- mechanical adjustable speed drive

- adjustable frequency drive
- adjustable voltage drive
- wound-rotor induction motor with liquid rheostat
- eddy current coupling
- hydraulic coupling

The selection of the appropriate type of speed control is dependent on speed range, cost, equipment mounting, compatibility with existing motor, space requirements, and efficiency. Other sources provide detailed information on selection of speed control equipment (2,39).

4.4.6.3 Time Clocks

Air-lift pumps are often used in package plants for returning sludge; however, control is often difficult. Frequently, high return sludge rates are maintained to avoid plugging. Excessively high return sludge rates commonly result in poor sludge settling conditions in the final clarifier and violation of SS permit limits. Improved control has been achieved with the addition of a solenoid valve on the air line to the air-lift pump with a time clock to control valve operation. This modification was successfully implemented at three package plants in Montana. Clarifier blanket levels decreased over 1.2 m (4 ft) at each plant, allowing each facility to meet their permit requirements.

A time clock can also be used to adjust the run time of oversized constant speed pumps. The motor manufacturer should be contacted to determine the maximum allowable motor starts per hour before this type of operation is initiated.

The use of time clocks to control the operation of return sludge pumps will be most beneficial when the associated clarifiers are being operated at low surface overflow rates. The use of intermittent recycle pumping introduces hydraulic transients in the final clarifier, and these transients can degrade the performance of a clarifier being operated at high surface overflow rates.

4.4.6.4 Multiple Pumps for Return Sludge Pumping

A common problem with plants that have a single, constant speed pump for returning sludge is that the pump is designed for a flow rate approaching design capacity. Start-up conditions and variable sludge characteristics require a return sludge pumping range of 25-125 percent of the influent flow rate. Typically, a single, constant speed pump is adjusted by throttling a discharge valve. This practice is not energy efficient and frequently results in plugging of the throttling valve. The use of multiple pumps of variable capacities can provide more flexible return sludge flow rates. This arrangement, when used in combination with some discharge valve throttling, results in reasonable variable return rate capability.

4.4.6.5 Flow Measurement

Continuous flow measurement capability is necessary to optimize return sludge control. The guidelines for return sludge flow measurement are similar to those discussed in Section 4.4.1.6. for waste sludge flow measurement.

4.4.7 Excessive Clarifier Hydraulic Currents

Extreme currents can develop as the result of density differences and the hydraulic characteristics of the clarifier inlets and outlets (40). The typical characteristics of currents in center-feed, peripheral overflow clarifiers is graphically shown in Figure 4-27. In this situation, the influent experiences a "water fall effect" whereby the flow drops to the clarifier bottom and moves along the top of the sludge blanket and up along the far end of the basin wall to the effluent weirs. As shown in Figure 4-28, this situation can also occur in rectangular clarifiers where the overflow weirs are located near the far end of the basin. Excessive currents can contribute to loss of solids at the effluent weir.

Figure 4-27. **Typical flow pattern for center-feed, peripheral overflow clarifier.**

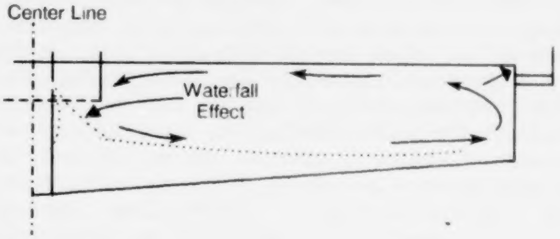
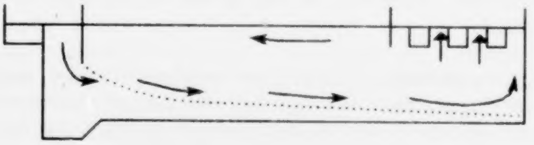


Figure 4-28. **Typical flow pattern in rectangular clarifier.**



Dye and SS testing can be used to identify excessive currents. These testing procedures have been utilized in field tests (41-43). Modifications to correct identified problems have produced mixed results. Modifications that have been utilized include changes to inlet structures and effluent weirs, and installation of baffles.

4.4.7.1 Inlet Modifications

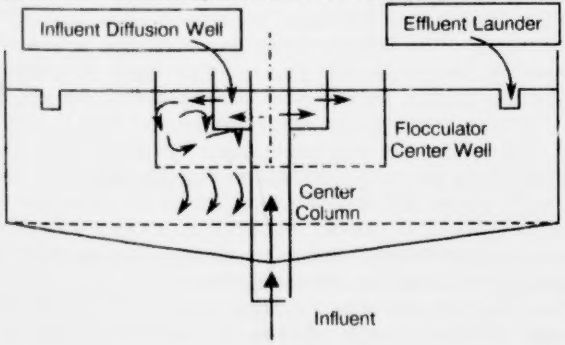
Inlet configurations are important to the proper performance of a clarifier. The ideal inlet should achieve both horizontal and vertical distribution of the incoming flow across the entire cross-sectional area, while minimizing short-circuiting and turbulence conditions (2). Inlets for circular clarifiers can be either a center or peripheral configuration. With the center feed configuration, the influent is introduced through either the side or bottom of a center feedwell. Center feed clarifiers with inlet pipes that enter the feedwell from the side can create asymetrical flow distribution. The influent to peripheral feed clarifiers is distributed through orifices located in an inlet raceway that extends around the periphery. Inlet configurations for rectangular clarifiers usually consist of baffled inlet ports or gates.

A research project at the Stamford, Connecticut wastewater treatment plant tested a full scale "distributed inlet" in one of the facility's center feed secondary clarifiers (44). The distributed inlet consisted of a full-depth feed well with baffled outlet ports spaced evenly from top to bottom. The special inlet design failed to produce a uniform flow pattern throughout the clarifier depth and actually resulted in a negative effect on performance.

Field experience with the modification of inlet structures to rectangular clarifiers has also resulted in little improvement. At the Herkimer, New York wastewater treatment plant, the vertical inlet baffles were installed in front of the inlet slots to reduce turbulence; however, the modification did not result in any detectable change in clarifier performance (43). Some improvement in performance was achieved from a small rectangular clarifier when an L-shaped reaction baffle was located in front of each inlet slot (41). The improved performance in this case was attributed to a reduction in scouring of the sludge sump.

A recent trend in secondary clarifier inlet design has included the enlargement of the center feedwell to form a flocculation chamber (40,45). Advantages claimed for the chamber are enhanced flocculation of incoming solids and dissipation of inlet energy. The concept of the flocculator-clarifer is shown in Figure 4-29.

Figure 4-29. Secondary clarifier with flocculating center well.



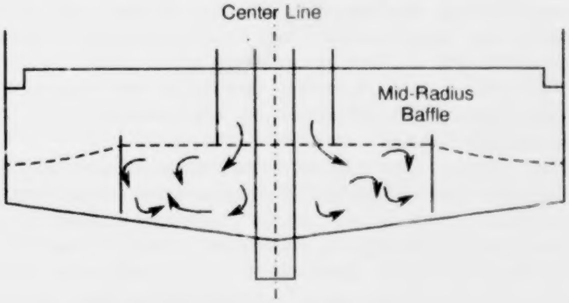
Influent enters the diffusion well, which is typically 10-13 percent of the tank diameter and closed at the bottom. Flow exits this compartment through adjustable side ports into the flocculator center well. By varying the gate openings in the diffusion well, the flocculating energy can be increased or decreased in the larger flocculator center well. Typically, the diameter of the flocculator center well is 25-35 percent of the tank diameter and results in a 20-30 minute detention time. The depth of this center well can be approximated as one-half the tank depth near its center for clarifiers with depths of 4.6 m (15 ft) or greater (40).

Performance data from both suspended growth and TF/SC plants utilizing flocculator-clarifiers show that effluents with average TSS concentrations of 10 mg/L or less can be achieved at overflow rates up to 48 $m^3/m^2/d$ (1,200 gpd/sq ft) (45). The flocculator-clarifier concept can be incorporated into an existing secondary clarifier. However, to realize the full benefits, a minimum depth of 4.6 m (15 ft) is recommended.

4.4.7.2 Baffle Addition

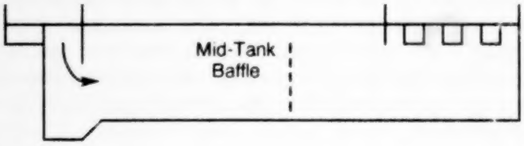
Recent field studies have shown that installation of mid-tank baffles can achieve some success in reducing the bottom currents and subsequently improving clarifier performance. Bender and Crosby (41) modified a 24.4-m (80-ft) diameter center feed, circular clarifier by installing a mid-radius baffle that extended from mid-depth to just off the clarifier bottom. The baffle rotated with the sludge collector mechanism. The mid-radius baffle configuration is shown in Figure 4-30. The effect of this baffle configuration was the creation of a floc center well and the breaking of the interface curents. Comparative studies showed a 37.5 percent reduction in TSS in the baffled clarifier.

Figure 4-30. Mid-radius baffle for circular clarifier.



Esler and Miller installed a mid-tank baffle in a 47.8-m (157-ft) long rectangular clarifier being used in a high-purity oxygen activated sludge plant (43). Dye studies conducted on the clarifier indicated a bottom current of 3.6 m (12 ft)/min and a reverse current at the surface of 1.5 m (5 ft)/min. The baffle was located from just below the water surface to slightly above the bottom sludge collection mech-anisms and consisted of 15-cm (6-in) plywood strips spaced 15 cm (6 in) apart for the bottom half of the baffle and 20 cm (8 in) apart for the top half. A schematic diagram is shown in Figure 4-31. Currents were reduced prior to the baffle, and little current detection could be identified downstream of the baffle. Comparative TSS tests showed a 20-39 percent improvement in removal efficiency. The baffle was relocated to the first third of the clarifier length, and continued to demonstrate improved performance. However, because of higher reverse currents in the downstream section of the clarifier, the mid-tank baffle was recommended over the "first third" baffle

Figure 4-31. Mid-tank baffle for rectangular clarifier.



The use of baffles near effluent weirs has also proven successful. Crosby (40) installed a baffle to direct flow away from a peripheral weir located on a 39.6-m (130-ft) diameter center-feed clarifier. This baffle configuration is shown in Figure 4-32a. A 38.3 percent decrease in SS was achieved over the effluent SS from a parallel clarifier without a baffle. Crosby recommends that the baffle be located no lower than 1/3 the distance from the weir to the bottom of the clarifier (42).

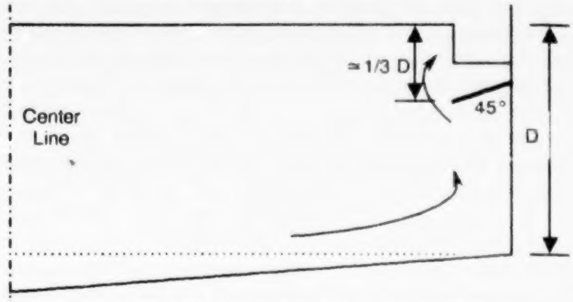
A horizontal weir baffle was modeled and studied by the University of Kansas (40). This configuration is shown in Figure 4-32b. The baffle extends horizontally from the edge of the effluent trough a distance of approximately two feet. As discussed in the following case history, sludge accumulation on the horizontal baffle may occur, which, in turn, could affect clarifier performance.

Case History: City of Helena, Montana Wastewater Treatment Facility

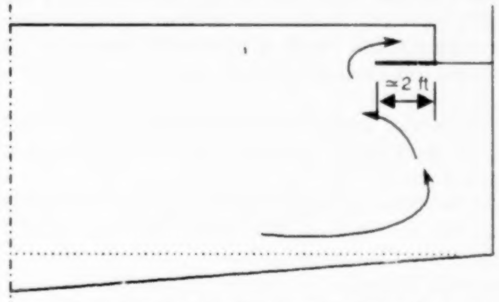
The Helena, Montana, wastewater treatment facility includes two 22.9-m (75-ft) diameter secondary clarifiers with a 3.2-m (10.5-ft) sidewater depth. The plant staff installed a deflection baffle along the periphery of the units to try and improve TSS removals. The horizontal fiberglass baffle was located approximately three feet below the water surface, and it extended approximately two feet out from the clarifier wall. The baffle was similar to the design shown in Figure 4-32a with the exception that the Helena baffle was installed perpendicular to the clarifier wall.

An improvement in effluent turbidity was observed; however, when the clarifiers were dewatered for inspection, approximately 15 cm (6 in) of sludge was detected on top of the horizontal baffles. The plant staff recommended that it would be advantageous to direct the baffle slightly downward to minimize deposition.

Figure 4-32. Baffled weir configurations.



a. Baffled Weir Demonstrated by Crosby (42)



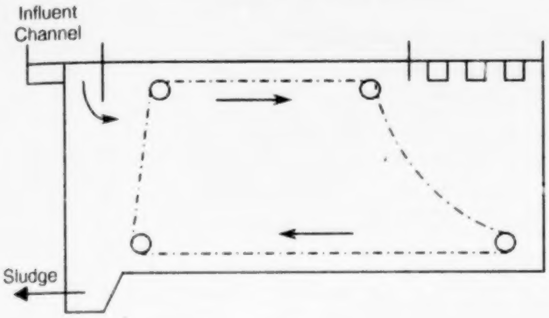
b. University of Kansas Horizontal Weir Baffle (40)

4.4.7.3 Weir Relocation/Addition

The relocation or addition of weirs can be used to improve clarifier performance. Rectangular clarifier weir location is usually dependent on the sludge collection mechanism. Figure 4-33 shows a cross-section of a typical rectangular clarifier with a sludge collector mechanism that travels from the back to the front of the clarifier. On the return trip, the mechanism travels along the surface to collect scum and then drops below the water surface to allow space for the weirs. This design limits the available space for overflow weirs. Solids loss in this type of clarifier typically occurs as the flow moves along the top of the sludge blanket, resuspending settled solids, which are carried up the end wall toward the weirs (43). This condition is shown graphically in Figure 4-28.

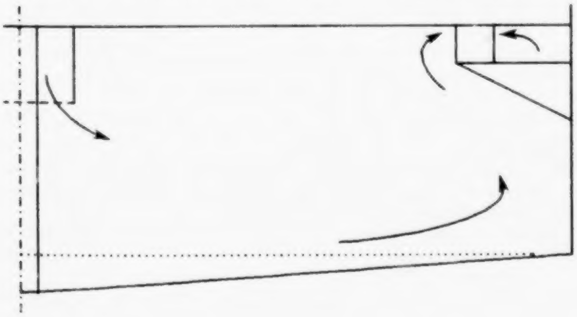
Providing additional weirs in rectangular clarifiers is usually not practical. In some situations, performance has been improved by blocking weirs that are located near the end walls. Research indicates that the velocity of the flow current along the top of the sludge blanket is considerably higher than near the overflow weirs; consequently, greater performance improvement may be achieved by taking steps to reduce the velocity of flow above the sludge blanket (42).

Figure 4-33. Typical rectangular clarifier.



The addition of weirs may be appropriate for center feed, peripheral overflow clarifiers that are experiencing solids loss. The flow pattern for this type of clarifier is shown in Figure 4-27. The flow radiates outward along the top of the sludge blanket and up the outside wall, frequently carrying solids over the weirs. One method of reducing the wall effect is to use cantilevered double or multiple weirs, as shown in Figure 4-34. Cantilevered weirs located a distance of at least 20 percent of the clarifier radius from the outside wall have reportedly worked well (40). The addition of a cantilevered weir could be an expensive modification because of the required new weir, structural supports, and changes to the scum collection mechanism. This modification does not allow mechanical scum removal for the annular area between the weirs and the side of the tank.

Figure 4-34. Center-feed clarifier with cantilevered weir.



4.4.8 Basin Mixing

Proper mixing is necessary to assure that mixed liquor solids are kept in suspension. Mixing is provided by diffused aeration equipment, mechanical aerators, or a combination of mechanical and diffused aeration equipment (i.e., submerged turbines). Inadequate mixing is seldom found to be a significant performance limiting factor even in cases where minor deposition of slids occurs. All other factors that could be affecting plant performance should be evaluated before any major modifications are made to improve mixing in an aeration basin. Aeration system design must consider the energy required to supply oxygen and to provide mixing. By meeting the requirements shown in Table 4-8, satisfactory mixing should be available in most aeration basins (2).

Table 4-8. Aeration Basin Mixing Requirements

Type of Equipment	Minimum Mixing Requirement
Fine Bubble Diffused Aeration	0.12 scfm/sq ft floor coverage
Coarse Bubble Diffused Aeration	20 scfm/1,000 cu ft
Mechanical	0.5 hp/1,000 cu ft

Correcting problems associated with inadequate mixing is limited to the addition of energy into the water or, in some cases, the use of baffles to redistribute energy in an existing basin. If additional energy is required in an aeration basin, the use of submerged or floating mechanical mixers should be investigated. Section 4.5.2.1 contains information on mechanical mixers.

4.4.9 Inadequate Scum Removal

Under some conditions significant scum can develop on the surface of both primary and secondary clarifiers. Typically, primary clarifiers are fitted with adequate scum handling equipment. However, scum handling equipment is frequently missing or undersized on secondary clarifiers. Scum accumulations can significantly contribute to effluent SS concentrations, especially in systems that operate at high mean cell residence times and do not have primary clarifiers (i.e., package plants).

Scum can be removed in aeration basins, channels, and clarifiers by the use of mechanical skimmers. The skimmers located in aeration basins, channels, and rectangular clarifiers typically consist of slotted pipe that can be rotated to collect scum from the water surface. Most scum collection designs for circular clarifiers include a rotating collection arm, a collection beach that is located near the periphery, and a scum baffle located adjacent to the weir. Scum moves to the outside of the clarifier surface where it is collected by the beach. If heavy scum conditions exist, much of the collected scum can pass under the collection beach and the scum baffle. Properly designed scum baffles should allow for a minimum of 15 cm (6 in) of baffle above and below the water surface, especially near the collection beach. The use of a full radius scum collection device is most effective since scum is removed across the full radius of the clarifier once per each revolution of the collector mechanism.

To be effective, scum should not be reintroduced to the system once it is removed. Removal can be accomplished by directing the scum to a solids handling process; however, scum frequently includes large volumes of water which can have a detrimental effect on solids handling. Scum volume can be reduced by installing a scum storage basin with decanting capability.

4.5 Wastewater Stabilization Ponds

Wastewater stabilization ponds are a commonly used treatment process for many small communities. Ponds are popular because of their ability to handle a wide range of hydraulic and organic loads with minimal effect on effluent quality, their relatively low capital cost, and their low operation and maintenance requirements. Types of wastewater stabilization ponds vary based on the method of mixing and aeration, the detention time, and the number and arrangement of individual cells. The two main types are facultative and aerated ponds.

Facultative ponds consist of medium depth [0.9-2.1 m (3-7 ft)] treatment cells that rely on photosynthesis and surface contact with the atmosphere for their source of oxygen. In aerated ponds, the depth of individual cells is 1.5-6 m (5-20 ft), and aeration is provided by a combination of mechanical aeration and natural processes. Detention time and organic loading for stabilization ponds is typically established by using empirical and rational design models. Additional design information is available from several sources (2,47,48).

Wastewater stabilization ponds utilize a variety of natural processes to treat the wastewater and, therefore, limited process controls are available to adjust system performance. Consequently, the ability of wastewater stabilization ponds to meet discharge limitations is largely dependent on the flexibility provided in the facility design.

Table 4-9 summarizes design limitations/corrective modifications that are prioritized based on their potential for achieving improved performance. Modifications with proven reliability and those that are less construction intensive appear at the beginning of the listing.

4.5.1 Undersized Ponds

Undersized ponds may be contributing to poor performance if a unit is operating at an organic loading rate higher than design for the type of facility in that climatic zone. Unfortunately, exact organic loading rates to meet performance requirements vary considerably. Table 4-10 summarizes typical design organic loading rates for wastewater stabilization ponds. In addition to these values, other factors such as aeration capacity, short-circuiting, and waste-water temperature must be carefully analyzed for their impact on facility performance.

In a community with industrial contributors, consideration should be given to pretreatment options before modifications are made. The following case history presents an example of the impact that an industrial waste can have on stabilization pond performance.

Table 4-9. Stabilization Pond Design Limitations and Potential Modifications

Design Limitation/Potential Modification	Page No.
4.5.1 Undersized Ponds	106
4.5.1.1 Improved Utilization of Existing Volume	108
4.5.1.2 Additional Treatment Cell Volume	108
4.5.1.3 Hydrograph Controlled Release	109
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4.5.6.1 Short-Term Diffused Aeration Cells	114

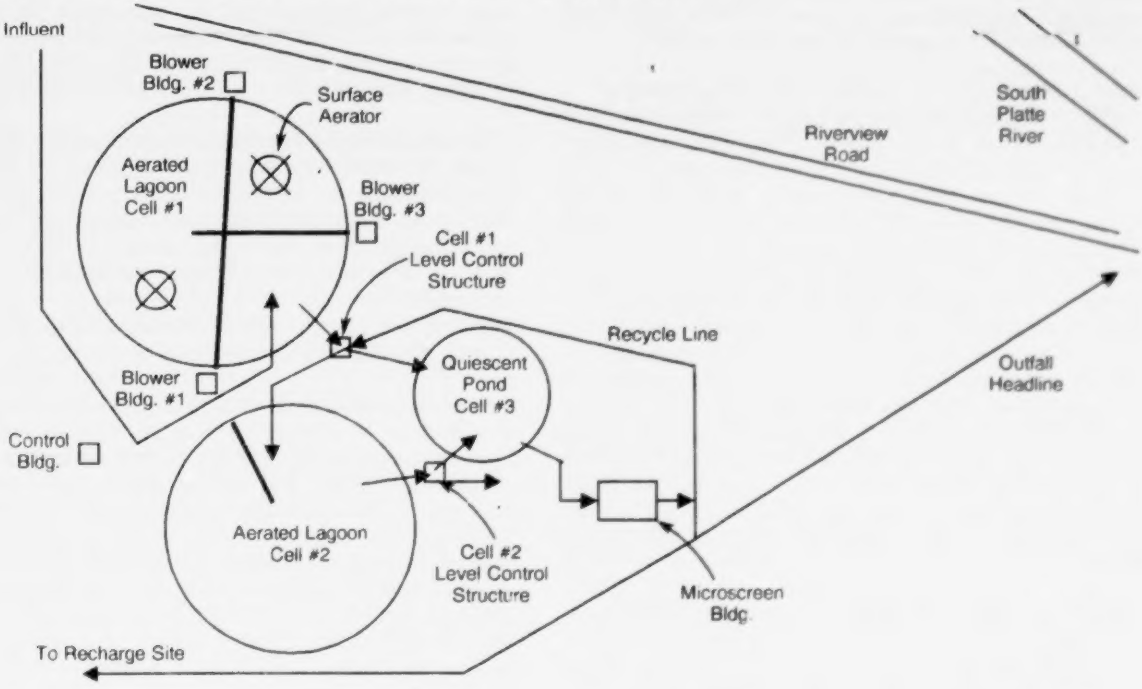
Table 4-10. Design Organic Loading Rates for Wastewater Stabilization Ponds

Source	Design BOD$_5$ Loading Rate
	kg/ha/d (lb/ac/d)
Facultative Ponds	
EPA Design Manual (47)	
Ave. Winter Air Temp. >15°C (59°F)	45-90 (40-80)
Max. first cell loading	101 (90)
Ave. Winter Air Temp. 0-15°C (32-59°F)	22-45 (20-40)
Ave. Winter Air Temp. <0°C (32°F)	11-22 (10-20)
Recommend detention time - first cell	120-180 days
Max. BOD$_5$ loading - first cell	37 (35)
Recommended Stds. for Sewage Works (50)	
Primary pond(s)	17-39 (15-35)
Aerated Ponds	
Metcalf & Eddy (49)	
Typical values (higher values also used)	34-112 (30-100)
EPA Design Manual (47)	
Loadings for case histories	86-184 (77-164)

Case History: City of Sterling, Colorado Aerated Stabilization Pond Facility (51)

The City of Sterling, Colorado provides wastewater treatment by the use of an aerated pond facility. The facility schematic is shown in Figure 4-35. Treatment is provided by two aerated cells and one settling cell. Aeration is provided by a diffused air system and supplemental surface mechanical aerators. The City has the flexibility to discharge treated water to recharge ponds or to a receiving stream. The design BOD$_5$ loading to the facility is 6,170 kg (13,600 lb)/d [560 kg/ha/d (500 lb/ac/d)]. A local meat packing

Figure 4-35. Schematic of Sterling, Colorado wastewater stabilization pond system.


Influent
Blower Bldg. #2
Surface Aerator
Aerated Lagoon Cell #1
Blower Bldg. #3
Cell #1 Level Control Structure
Riverview Road
South Platte River
Recycle Line
Blower Bldg. #1
Quiescent Pond Cell #3
Outfall Headline
Control Bldg.
Aerated Lagoon Cell #2
Cell #2 Level Control Structure
Microscreen Bldg.
To Recharge Site

industry accounts for up to 80 percent of the BOD_5 loading. The industry has on-site pretreatment facilities (e.g., air flotation with chemical feed equipment) which are capable of removing 70 percent of the BOD_5 load.

Prior to 1986, minimal efforts were made by the industry to operate their pretreatment facilities, and, as a result, design BOD_5 loadings to the city's facility were frequently exceeded. During the end of 1986 and all of 1987, the industry placed a higher priority on operation of the pretreatment equipment to reduce their surcharge costs to the City. As shown in Table 4-11, a 39 percent decrease in BOD_5 loading was achieved in 1987 versus 1986 loadings. The TSS loading decreased by 27 percent during this same period.

Prior to improved operation of the pretreatment equipment, aeration capacity at the city facility was frequently inadequate. During the high loading period in 1986 (January-July), the DO level in the first aerated cell was near zero. With improved pretreatment, the aeration equipment at the facility was capable of achieving a residual DO of about 2 mg/L in the first cell.

Table 4-11. Loading to the Sterling, Colorado Wastewater Stabilization Treatment Facility

Month	1986 (lb/d)		1987 (lb/d)	
	TSS	BOD_5	TSS	BOD_5
January	16,589	14,091	10,644	7,554
February	20,201	17,554	12,643	10,452
March	20,894	20,566	12,893	12,003
April	18,954	15,755	5,100	6,231
May	17927	14,610	2,607	3,809
June	15,013	11,976	5,861	7,175
July	13,870	10,870	8,774	11,064
August	9,491	7,188	9,583	11,739
September	13,324	10,927	9,459	9,543
October	11,685	10,647	10,390	9,531
November	10,839	9,099	10,090	11,102
December	9,085	6,815	9,915	8,842
Average	14,822	12,508	8,997	9,087

Performance of the city's facility has improved. In 1986 the average BOD_5 and TSS concentrations from the settling cell were 37 mg/L and 34 mg/L, respectively. In 1987, these values decreased to 31 mg/L and 20 mg/L. Periodic performance problems still occur because of significant sludge deposits located in the first and second treatment ponds. The operations staff is currently experimenting with mixing equipment to reduce the effects of these sludge deposits on performance.

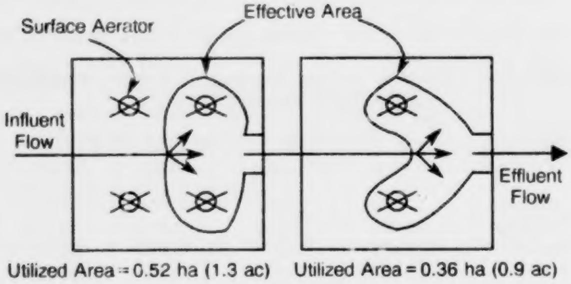
If administrative solutions to correct a loading problem, such as the previous pretreatment case history, are not feasible, modifications to the wastewater stabilization facility will probably be required. The following sections present information on modifications to correct undersized ponds.

4.5.1.1 Improved Utilization of Existing Volume

Short-circuiting is a common problem that occurs with wastewater stabilization ponds. This topic is discussed in Section 4.5.3; however, it is mentioned here since, in many cases, it is more cost effective to correct short-circuiting than to construct additional ponds. When short-circuiting occurs in wastewater stabilization ponds, the actual total volume in the ponds is not used effectively. Short-circuiting can exist because of pond configuration and temperature stratification. An example of poor pond configuration is shown in Figure 4-36. The design BOD_5 loading for this facility is 168 kg/ha/d (150 lb/ac/d); however, because of the location of inlet pipes and the square shape of the cells, the effective volume of the ponds is substantially reduced. In this example, the BOD_5 loading could conceivably be as high as 526 kg/ha/d (470 lb/ac/d), or about three times the design loading rate

Figure 4-36. Effect of short-circuiting on organic loading.

Flow = 22 L/s (0.5 mgd)
BOD_5 = 250 mg/L
Design Organic Loading = 168 kg/ha/d (150 lb/ac/d)


Effective Area
Surface Aerator
Influent Flow
Effluent Flow
Utilized Area = 0.52 ha (1.3 ac)
Utilized Area = 0.36 ha (0.9 ac)

Probable BOD_5 Load @ Design Conditions = 526 kg/ha/d (470 lb/ac/d)

Short-circuiting effects shown in Figure 4-36 could be improved through modification to the cell inlets and installation of baffles to form three or more treatment cells. Section 4.5.3 provides information on installing baffles in existing ponds.

Temperature stratification in facultative ponds occurs during the spring and fall of the year and can result in ineffective utilization of treatment volume. During these periods, improved mixing can be used to maintain desired system performance. Section 4.5.3.2 includes information on the use of mechanical mixers in ponds.

In older stabilization ponds or in heavily loaded facilities, the volume available for treatment can be reduced significantly because of solids deposition. This situation typically occurs in the initial treatment cells. Solids removal can be accomplished through dewatering the cells and removing the dry solids, or by pumping the solids from the cell with the use of dredging equipment.

4.5.1.2 Additional Treatment Cell Volume

Additional cell volume will be required to improve performance if addressing short-circuiting is ineffective. Several design approaches are available for sizing pond systems, including: 1) Areal loading rate, 2) Gloyna equation, 3) Marais & Shaw equation (complete mix model), 4) Plug flow model, and 5) Wehner-Wilhelm equation. Descriptions of these approaches are presented elsewhere (47).

Additional cell volume can be achieved by expanding the volume of existing cells or by adding new cells. The performance of existing systems and the design equations indicate that overall performance improves with the number of cells in series; consequently, it is recommended that additional cells be added. The following design example, using the complete mix model, demonstrates the approach for adding cell volume:

Design Example:

Description of Existing Pond System:

Design Flow = 22 L/s (0.5 mgd)
Influent BOD_5 = 200 mg/L
Effluent BOD_5 Limit = 30 mg/L

First Cell Volume (aerated) = 22,710 m^3 (6,000,000 gal)
Second Cell Volume (aerated) = 22,710 m^3 (6,000,000 gal)
Critical Cell Temperature = 1°C (34°F)
Reaction Coefficient k (base 10) @ 20°C = 0.2 d^{-1}
Reaction Coefficient k (base 10) @ 1°C = 0.042 d^{-1}
Detention Time (t) 1st & 2nd Cells = 12 d

Expected Performance from Existing System per Complete Mix Equation:

$$C_e = C_i \div (1 + 2.3kt)$$

First Cell Effluent BOD_5 = 93 mg/L
Second Cell Effluent BOD_5 = 43 mg/L

Alternative 1: Increase the system volume by adding 15,140 m^3 (4,000,000 gal) of capacity to the first cell and 7,570 m^3 (2,000,000 gal) to the second cell.

First Cell Volume (aerated) = 37,850 m^3 (10,000,000 gal)
First Cell Detention Time (t) = 20 d

Second Cell Volume (aerated) = 30,280 m^3 (8,000,000 gal)

Second Cell Detention Time (t) = 16 d

First Cell Effluent BOD_5 = 68 mg/L

Second Cell Effluent BOD_5 = 27 mg/L

Alternative 2: Increase the system volume by adding a third cell with a volume of 22,710 m^3 (6,000,000 gal). No changes to the first and second cells.

First Cell Volume (aerated) = 22,710 m^3 (6,000,000 gal)
Second Cell Volume (aerated) = 22,710 m^3 (6,000,000 gal)
Third Cell Volume (aerated) = 22,710 m^3 (6,000,000 gal)

First Cell Effluent BOD_5 = 93 mg/L
Second Cell Effluent BOD_5 = 43 mg/L
Third Cell Effluent BOD_5 = 20 mg/L

The model indicates better performance can be expected from the three-cell modification (i.e., Alternative 2) than from the expanded two-cell modification (i.e., Alternative 1) even though both alternatives increase total cell volume by the same amount.

4.5.1.3 Hydrograph Controlled Release

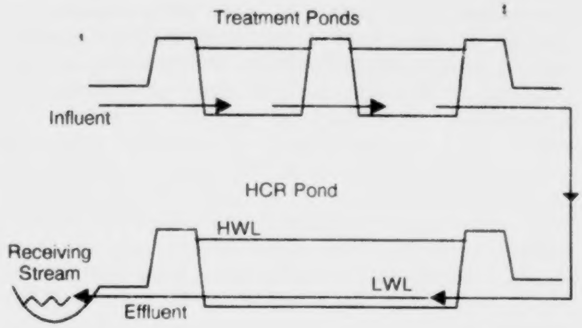
Hydrograph-controlled release (HCR) systems can be used to allow pond facilities to meet discharge requirements by managing the discharge of wastewater in accordance with the receiving stream's assimilative capacity (80,107). An HCR facility restricts discharge when flow in the receiving stream is low and stream assimilative capacity is limited. Conversely, as flow increases, previously stored flow is released. HCR system components include an HCR lagoon, stream flow monitoring system, and effluent discharge system.

A schematic of a pond facility incorporating the HCR concept is shown in Figure 4-37. HCR ponds are designed for variable depth operation (i.e., minimum depth of 0.6 m (2 ft), maximum depth of 2.4 m (8 ft)). Pond size is related to both stream and plant flows. Detention times in the pond can typically range from 30 days to in excess of 120 days, based on the average plant flow (80).

Existing facilities can be modified to operate with HCR flexibility if they have sufficient storage volume. Modifications to the effluent control structure will probably be required. If sufficient storage volume does not exist, expansion of existing ponds or the addition of a new pond would be required.

In some cases, local regulatory agencies may not allow plant discharges to be varied in accordance with stream flow. The capability of obtaining a flow-regulated permit must be established prior to consideration of the HCR alternative.

Figure 4-37. Wastewater stabilization pond system with HCR flexibility.



4.5.1.4 Aquaculture

Aquaculture can be used to improve performance of existing wastewater stabilization ponds. The Brazilian water hyacinth, which is commonly used in aquaculture systems located in sub-tropical and tropical regions, is very sensitive to temperature and does not grow in water with a temperature of 10 °C (50°F) or lower (53). The American hyacinth, however, is more cold-tolerant (106). Use of water hyacinths requires consideration of loading rate, pond depth, plant harvesting, and disposal. A wastewater stabilization pond facility could utilize water hyacinths in an existing cell, or a new cell(s) could be constructed.

Water hyacinth treatment systems have produced effluents meeting secondary standards when loaded at 31-197 kg BOD/ha/d (28-176 lb/ac/d) (52). In cases where frequent harvesting is practical and good contact between plants and nutrients is attained, significant nitrogen and phosphorous removal can also be achieved. Depths of hyacinth ponds vary from 0.3 to 1.8 m (1 to 6 ft), with 0.9 m (3 ft) being commonly recommended. Good practice calls for the root system of the water plants to penetrate the entire depth.

The main disadvantage of utilizing water hyacinths is the harvesting and disposal requirements for the excess plants. These plants are very prolific, and harvesting is required at least once per month during rapid growing seasons and more frequently if significant nutrient removal is a treatment objective. For small communities, the use of solids handling processes such as digestion and composting to treat the excess hyacinths may not be feasible. Storage or disposal of the excess hyacinths on site frequently results in the production of odors and unsightly conditions. Unless a reliable method of excess hyacinth disposal is available, other modifications to correct the undersized ponds should be investigated.

The use of the duckweed plant in stabilization ponds has been proposed for removal of TSS and associated BOD_5 nutrients, and heavy metals (53). Duckweed plants form a mat over the pond surface, and under the right conditions, this mat can be very effective in blocking sunlight from penetrating the pond, thus controlling the growth of algae. The presence of a duckweed results in anaerobic conditions due to the lack of surface reaeration and the low oxygen production from the duckweed plants. If an existing pond system is to be retrofitted to include duckweed for solids control, consideration should be given to the reduced volume available for BOD_5 removal. Consequently, if soluble BOD_5 removal is part of the performance problem, the use of duckweed may not be appropriate. Duckweed appears to be most applicable for situations where algal solids present TSS problems (54). The use of duckweed for the control of algae is discussed in Section 4.5.4. Other innovations in the use of aquaculture can be found in *Design Manual: Constructed Wetlands and Aquatic Plant Systems for Municipal Wastewater Treatment* (108).

4.5.2 Inadequate Oxygen Transfer Capability
Facultative pond systems utilize photosynthesis and surface contact with the atmosphere to provide the necessary oxygen for the treatment process. If facultative ponds become deficient in oxygen due to overloading, supplemental aeration can be added by the use of surface mechanical aerators or diffused aeration systems. Caution is advised when trying to incorporate mechanical aeration equipment into facultative pond systems. The shallow depth found in most ponds is not suitable for diffused aeration systems because of the low transfer efficiency, and the installation of surface mechanical aerators can result in erosion damage to the pond bottom. Because of these disadvantages it may be more appropriate to investigate additional pond volume.

Aerated pond systems typically rely on mechanical aeration equipment to supply oxygen and mixing. Aeration requirements are usually determined by multiplying the expected BOD_5 removal per treatment cell by an oxygen demand factor (e.g., 1.5 kg O_2/kg BOD_5 removed is a commonly used value). Horsepower required is determined by converting standard oxygenation rates for specific equipment to actual oxygenation rates. This procedure is presented in Appendix F.

4.5.2.1 Mechanical Mixers
Frequently, the horsepower included in an aerated cell is provided to meet the oxygen requirement with little attention given to mixing. As such, the horsepower provided can be considerably less than that required for complete or even partial mixing. Limited mixing capability results in inadequate dispersion of available oxygen throughout the entire cell volume.

Mechanical mixers can be used to enhance oxygen transfer in a poorly mixed aerated cell. Typically, with surface mechanical aerators, only 40-50 percent of the shaft energy is actually applied to mixing. In contrast, surface mechanical mixers apply almost all of the shaft energy for mixing. It is estimated that the mixing capability of surface mechanical mixers is two to three times greater than the mixing capability for surface mechanical aerators of the same horsepower (56).

4.5.2.2 Additional Aeration Equipment
Types of aeration equipment utilized in aerated pond systems can be described as either surface mechanical or diffused aeration. Detailed information on available aeration equipment can be obtained from other sources (2,48). Selection of supplemental aeration equipment is dependent on the existing system, energy requirements, cold weather operation, installation requirements, and O&M requirements.

Surface mechanical aerators can be added while the facility remains in operation. Installation requires an electrical power connection and mooring of the aerator to the banks. In cold climate areas, ice build-up can result in equipment failure; however, heaters can be installed to limit this condition. Those aerators that utilize submerged motors or that inject air into the water (aspirator type) typically do not experience significant cold weather problems.

Diffused aeration systems can be considered where sufficient pond depth is available to provide oxygen transfer (e.g., depths greater than eight feet). Installation of a diffused aeration system typically requires dewatering; consequently, flexibility is needed to bypass during installation. Occasionally, diffuser breakage will occur; therefore, some method of repairing and monitoring the difference must be provided. Diffused aeration systems have an advantage over most surface mechanical systems in conserving wastewater temperature. This advantage is discussed in more detail in Section 4.5.5.

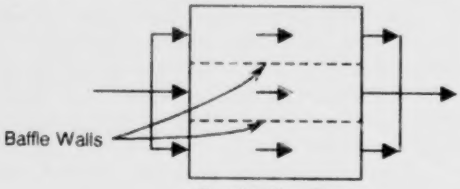
4.5.3 Short-Circuiting
Short-circuiting is a common problem in wastewater stabilization ponds. Impact of this problem on effective utilization of pond volume was discussed in Section 4.5.1.1. Other effects include ineffective use of aeration equipment, promotion of algae growth in quiescent areas, and scum accumulation. In many wastewater stabilization ponds, existing performance can be improved by minimizing short-circuiting.

4.5.3.1 Baffles
The most effective method of correcting short-circuiting is the use of baffles. Various materials have been used for baffle walls including metal, fiberglass, and plastic. Recently, several manufacturers have introduced baffles made of reinforced plastic material that are supported by a continuous float at the water

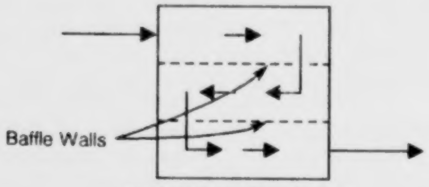
surface and a chain weight at the bottom. Each baffle wall is held in place by anchors located at the pond dikes. Accurate field measurements must be taken to determine the correct length and depth of individual baffle walls since the depth of water may vary slightly because of sludge deposits. Designs should also include consideration for icing conditions that can cause damage to the baffle walls.

Numerous flow configurations can be achieved with baffles. Two possible configurations are shown in Figure 4-38. In the parallel pattern, baffle walls are used to divide an existing cell and thus the influent load into three separate cells. This arrangement can be used when additional dilution of a high strength waste is desirable at the beginning of the first treatment cell. In the serpentine arrangement, baffle walls are used to form a plug flow pattern through the existing cell. This arrangement does not require flow splitting and often better performance can be expected because of the multiple cells in series. Organic loading is highest at the beginning of the first cell, and decreases gradually through the system. Aeration equipment must be proportioned accordingly to meet the anticipated oxygen demand.

Figure 4-38. Modification of ponds with baffle walls.



a. Parallel Flow Pattern



b. Serpentine Flow Pattern

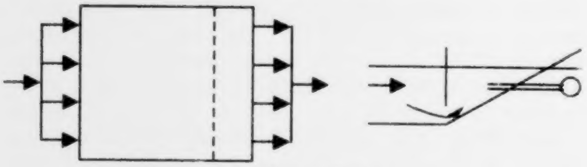
4.5.3.2 Mixing Equipment

Short-circuiting can be reduced by the addition of more mixing energy. Guidelines for power requirements for mixing can be found in several sources (2,47,56). A minimum power level of 0.0004 KW/m^3 (2 hp/Mgal) is recommended for oxygen dispersion in aerated ponds, and a minimum power level of 0.003 W/m^3 (15 hp/Mgal) is recommended to maintain solids in suspension (56). Equipment manufacturers should be contacted for specific information.

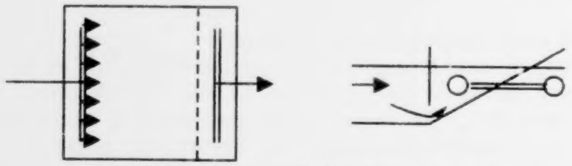
4.5.3.3 Multiple Inlets and Outlets

The existence of only one inlet and one outlet in a square cell configuration can be a major factor contributing to short-circuiting, as shown in Figure 4-36. Multiple inlets and outlets can improve utilization of cell volume. Figure 4-39 illustrates four inlet and outlet points provided along the full width of the cell. More positive control of flow distribution could be accomplished by including valves on the individual inlets and outlets. Dispersion could then be optimized by utilizing a dye study to indicate appropriate valve adjustments. Figure 4-39b illustrates the use of distribution pipes with orifices for the inlet and outlet structures. This approach would provide more even distribution than the multiple inlet/outlet alternatives. The inlet and outlet orifice pipes must be hydraulically designed to equally distribute and collect the wastewater. Primary ponds as large as 36 ha (90 ac) have successfully used this type of flow distribution for over 20 years (47).

Figure 4-39. Inlet/outlet configurations.



a. Multiple Inlet/Outlet



b. Inlet and Outlet Pipes w/Orifices/Effluent Baffle

4.5.4 *Inadequate Suspended Solids Control*

High concentrations of algae and the resulting high SS levels in wastewater stabilization ponds periodically affect the performance of these facilities. This situation typically occurs during warm weather conditions which promote the growth of algae, and it is also cyclical during this time as the predominance of various organisms in the system changes. A variance is allowed in the Federal TSS effluent requirements for pond systems less than 44 L/s (2 mgd) in capacity. However, even with this variance, effluent TSS levels can occasionally exceed discharge permit limits.

Alternatives available for the control of TSS in pond effluents include:

- Chemical addition
- Controlled discharge
- Aquaculture
- Variable level draw-off
- Intermittent sand filtration
- Land application (except overland flow)

A comprehensive review of available technology can be found in *Design Manual: Wastewater Stabilization Ponds* (47). The following approaches can be implemented before more capital intensive alternatives are recommended.

4.5.4.1 Controlled Discharge

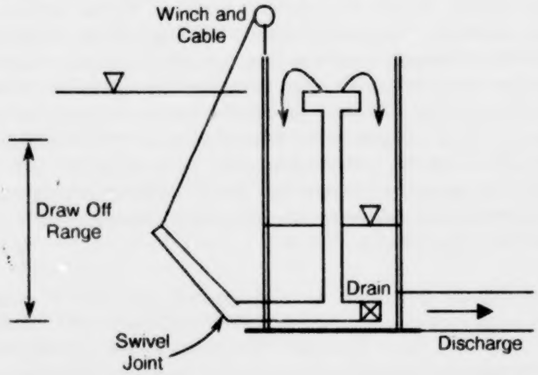
Controlled discharge of pond effluent can be an effective means of meeting effluent TSS limitations for facilities that have sufficient volume to store wastewater for an extended period of time (e.g., one to three months). Studies of controlled discharge from facilities in Michigan and Minnesota have shown that effluent TSS concentrations of less than 30 mg/L can be achieved (47). Section 4.5.13 includes information on hydrograph-controlled release facilities.

For wastewater stabilization ponds that are not designed to allow controlled discharge, the selective release of wastewater from multiple treatment ponds frequently can be an effective approach to controlling effluent TSS. In multiple pond systems, it is not uncommon for effluent quality in a middle pond to be superior to that in the final pond. By drawing down the "clean pond," it is possible to obtain storage volume. This approach requires the flexibility to discharge from multiple ponds and the ability to draw these ponds down to the desired levels.

4.5.4.2 Variable Level Draw-Off

In stabilization ponds with depths greater than six feet, variable level effluent draw-off can be effective in controlling TSS. Algae growth decreases at increasing pond depths because of the limited light penetration. A schematic view of a variable level draw-off structure is shown in Figure 4-40. A pipe connected to a swivel joint provides the flexibility to remove effluent from various depths while an overflow weir located in the control structure establishes the pond operating level.

Figure 4-40. Variable level draw-off structure.



4.5.4.3 Aquaculture

Aquatic plants can be utilized to control algae growth because of their ability to block sunlight penetration. Both water hyacinths and duckweed have been reported as being effective in controlling the growth of algae (52-54). The practice of aquaculture requires consistent attention to the growth of the aquatic plants, and significant effort is required to harvest, process, and dispose of excess plants. Because of these operational-intensive requirements, aqua-culture is typically not recommended as a modification for small pond systems. This practice may be viable at larger stabilization ponds that have the needed staff. Refer to Section 4.5.1.3 for information on the use of hyacinths for wastewater treatment.

Duckweed (*Lemna sp.*) is a small, green freshwater plant with a leaflike frond that is a few millimeters in width, and with a short root that is less than one centimeter in length. *Lemna sp.* grown in wastewater effluent at 17°C (63°F) double in frond numbers every four days. Duckweed is more tolerant of colder temperatures than water hyacinths. A minimum temperature of 7°C (45°F) has been suggested as the practical lower limit for considering the use of duckweed. During freezing conditions, duckweed lies dormant on the pond bottom. The high protein and fat content of duckweed make the partially dried plants an attractive food source for animals (54).

A patented treatment process called the LEMNA system can utilize existing pond structures in conjunction with floating surface barriers and hydraulic membranes to add aquaculture capability to a facility (53). With this process the duckweed are contained within confined surface areas by floating barriers which limit the turbulent effects of wind. The hydraulic membranes are attached to the floating barriers and are weighted to sink to the pond bottom. The membranes are used to distribute the flow evenly throughout the pond. The duckweed mat significantly reduces sunlight penetration into the pond, which limits algae growth and thus TSS concentrations.

Duckweed was used in an existing wastewater stabilization pond in Gilcrest, Colorado. Small, multiple cells are utilized for infiltration of the treated effluent rather than settling. Partial plugging at the soil/water interface results in a water level of 0.3-0.6 m (1-2 ft) in the cells at all times. During summer months duckweed is grown on the surface of the infiltration cells. When the duckweed cover is present, TSS concentrations of the treated effluent in these cells generally remain below 10 mg/L. Direct discharge from these cells would meet a 30 mg/L TSS standard.

The following design considerations are taken from successfully operating systems (54):

- For algae control, a minimum detention time of 20 days should be used for the duckweed-covered portion of the ponds to allow sufficient time for existing algae to die and settle.

- A baffled compartment with a length to width ratio of 10:1 or more is recommended to encourage plug flow conditions.

- Post aeration may be required since anaerobic conditions will develop under the duckweed mat.

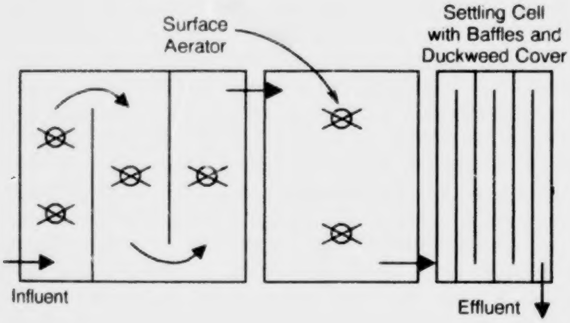
- Discharge from the duckweed-covered portion of the pond should be located below the water surface to minimize the removal of duckweed plants.

- Regular harvesting (e.g., monthly for secondary treatment) is recommended to control the decomposition of dying plants. Specialized harvesting equipment is commercially available.

- A backup system, such as intermittent sand filtration, may be necessary to provide consistent (tertiary) effluent quality.

A schematic of a pond system utilizing duckweed for algae control is shown in Figure 4-41.

Figure 4-41. Stabilization pond system utilizing duckweed cover.


Surface Aerator
Settling Cell with Baffles and Duckweed Cover
Influent
Effluent

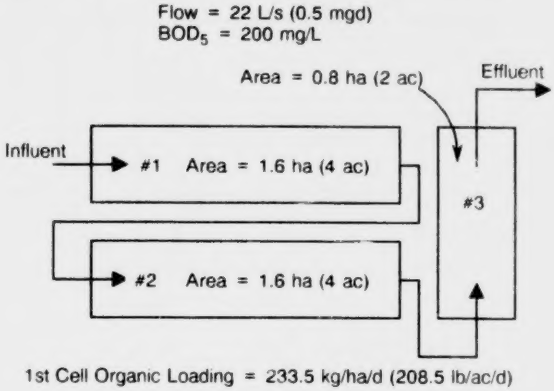
4.5.5 Inflexible Mode of Operation

For facilities that receive periodic high organic loading, it is sometimes advantageous to split incoming wastewater flow to more than one treatment cell. Recirculation of a treatment cell effluent back to a previous cell can have a similar effect in that the influent organic strength is diluted by the recirculation flow.

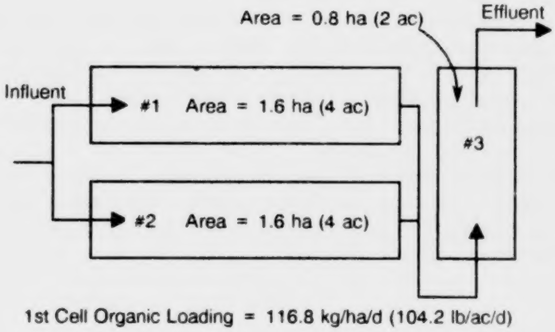
4.5.5.1 Series/Parallel Operation

Under most circumstances it is more advantageous to operate a stabilization pond system in a series pattern instead of in a parallel pattern. However, at facilities that have limited aeration capacity, the first treatment cell in a series operation can become organically overloaded, and anaerobic conditions can develop. The ability to split the incoming wastewater flow to more than one treatment cell is shown in Figure 4-42. With the modification shown in Figure 4-42b, the first two treatment cells can be operated in either a series or parallel mode. By operating in the parallel mode, the organic loading to the first treatment cell can be reduced by 50 percent.

Figure 4-42. Series and parallel operational flexibility.


Flow = 22 L/s (0.5 mgd)
BOD5 = 200 mg/L
Area = 0.8 ha (2 ac)
Effluent
Influent
#1 Area = 1.6 ha (4 ac)
#2 Area = 1.6 ha (4 ac)
#3
1st Cell Organic Loading = 233.5 kg/ha/d (208.5 lb/ac/d)

a. Series Operation


Area = 0.8 ha (2 ac)
Effluent
Influent
#1 Area = 1.6 ha (4 ac)
#2 Area = 1.6 ha (4 ac)
#3
1st Cell Organic Loading = 116.8 kg/ha/d (104.2 lb/ac/d)

a. Parallel Operation

4.5.5.2 Recycle Capability

Recirculation is utilized in stabilization ponds that periodically or seasonally receive high strength organic wastes. Advantages include: 1) dilution of the incoming wastewater strength, 2) return of active algal cells to the primary treatment pond to provide photosynthetic oxygen, and 3) mixing of the pond contents to reduce the effects of stratification. A flexible recirculation system is shown in Figure 4-43. The first two treatment cells can be operated using either series or parallel flow patterns, and the recirculation flow can be taken from either the first or second cells or from both cells. Typically, high-volume, low-head propeller pumps are used. Information on recirculation pump stations can be found elsewhere (47).

A disadvantage of pond recirculation is the energy cost. Therefore, other modifications, such as additional aeration, mixing, or additional pond volume may be more cost effective.

Figure 4-43. Stabilization pond system with recirculation flexibility.

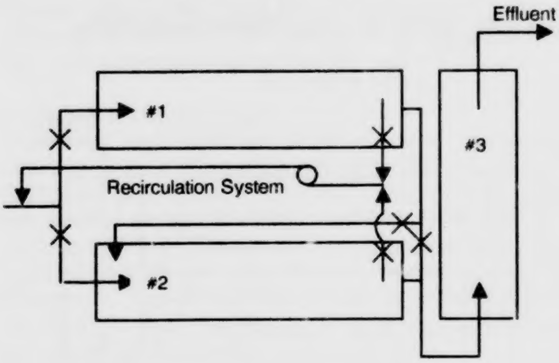
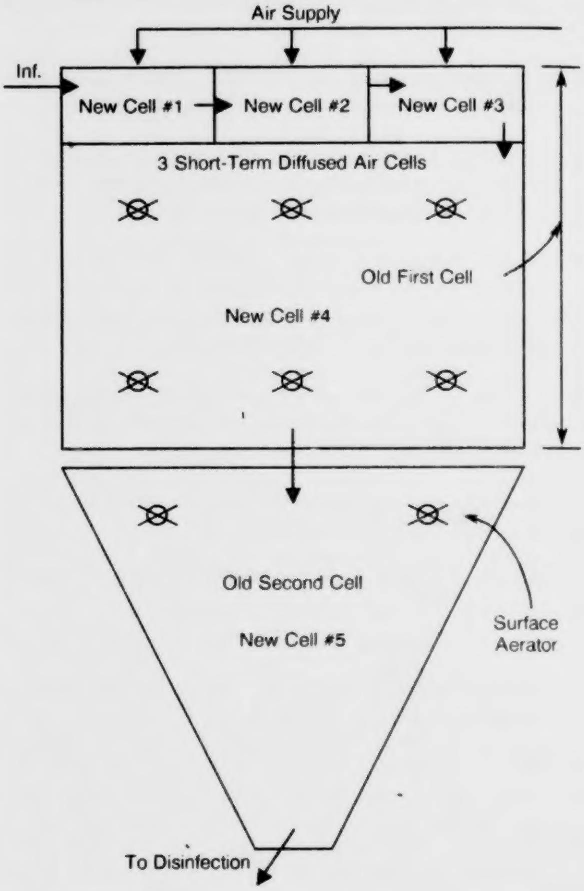


Figure 4-44. Modifications to existing two-cell pond.



4.5.6 *Low Pond Temperature*

Continuous discharge pond systems that are subject to extended periods of cold weather often violate their BOD_5 and TSS limits since biological activity decreases significantly during these periods. Aeration equipment can also contribute to cold weather performance problems. Some types of surface mechanical aerators and brush-type aerators are subject to ice build-up. Other aeration equipment may contribute to low pond temperatures through heat loss from the aeration process.

4.5.6.1 Short-Term Diffused Aeration Cells

Performance could be improved in pond systems if the influent wastewater temperature could be conserved through the facility. Short-term, diffused aeration cells can be used to partially achieve this objective. The short-term cells should be designed to maintain the wastewater temperature above freezing. Two to three short-term cells are recommended to minimize short-circuiting and maximize BOD_5 removal. A diffused aeration system avoids the contact of the treatment cell contents with cold air, and actually provides a small amount of heat to the water from the compressed air.

An aerated pond facility located in Woodland Park, CO, was modified to include three, short-term cells, as shown in Figure 4-44. The short-term cells were formed by installing baffle walls in the primary cell. Each cell has a wastewater depth of about 1.8 m (5.5 ft) and was designed for a detention time of two days. Aeration is provided by two positive displacement blowers, air piping, and rubber-membrane, fine bubble diffusers. The existing surface mechanical aerators were fitted with heaters and relocated in the large ponds. All modifications to the existing system were made while the facility remained in operation. At the time of the modification, the wastewater flow to the facility ranged from 7.9 to 11.0 L/s (0.18-0.25 mgd).

During the winter season following the modification, some improvement in performance over the previous winter occured; however, the facility still, exceeded their 30-mg/L BOD_5 effluent limit during January and February. Following this period the facility staff discovered that a flap gate between treatment cell 1 and cell 4 had remained open, thus allowing some of the influent to escape the short-term treatment cells. Total effectiveness of the modification therefore has not been determined.

4.6 Sludge Treatment and Disposal

4.6.1 Background

Sludge handling limitations have a significant impact on achieving desired performance from existing wastewater treatment facilities (57). This section defines alternatives for addressing the common deficiencies observed. Guidance for addressing proposed new sludge regulations being developed by the U.S. EPA and State's government agencies are not included. These regulations probably will require more stringent levels of treatment than presently exist plus provide additional restrictions for ultimate disposal practices.

Data from operating facilities have indicated that an individual plant's sludge handling problem was often multifaceted (i.e., more than one aspect of the total sludge handling capability would be identified as a deficiency). Two broad areas of deficiencies were identified: 1) inappropriate assessment of sludge production (i.e., mass, volume and variability), and 2) lack of process flexibility.

4.6.1.1 Sludge Production

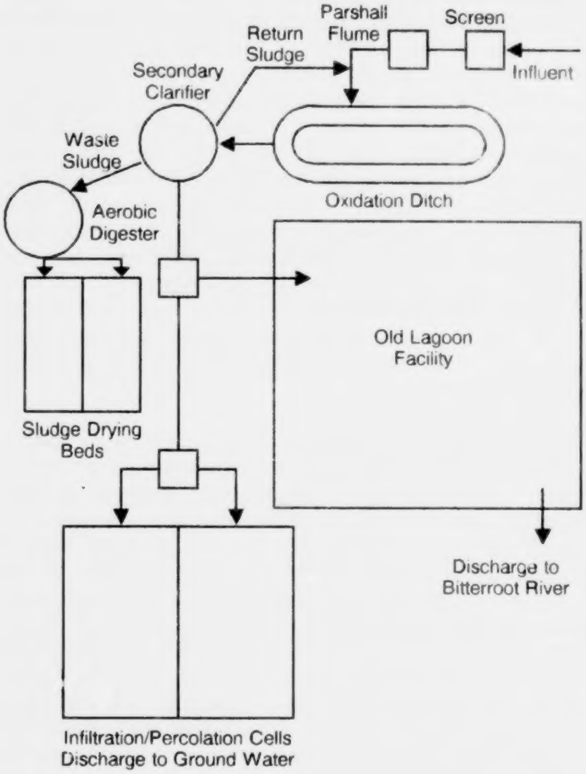
Much information is written concerning sludge production in terms of mass and volume and, to some extent, on the variable nature of sludge produced (48,49,59,62,94,95). Ranges in published information are believed to contribute to observed limitations. The designer has the option to select criteria on the low end of published values resulting in economically sized facilities at the expense of limiting capability to handle variations from the design values. Additionally, sludge handling limitations are often masked by a plant's capability to store quantities of sludge within the wastewater treatment unit processes (e.g., clarifiers, thickeners, digesters, and aeration basins) and by the fact that new facilities often receive loadings less than design. A preliminary assessment of the capability of the sludge handling facilities can be achieved by completing a sludge accountability analysis. (See Section 2.3.5.1.)

In order for a plant to meet effluent performance criteria on a consistent basis, the sludge handling facilities must be provided with adequate capacity to handle the mass, volume, and variability of sludge produced. The following case study illustrates the effects of limited capability.

Case Study: The Effects of Limited Sludge Handling Capability on the Stevensville, Montana Wastewater Treatment Plant (58)

The Stevensville, Montana wastewater treatment plant is an oxidation ditch facility that was designed for an average daily flow of 13.1 L/s (0.3 mgd). Secondary effluent from the oxidation ditch process is directed to two infiltration/percolation (I/P) ponds for direct discharge to ground water. A layout of the treatment plant is shown in Figure 4-45.

Figure 4-45. Schematic of Stevensville, Montana WWTP.



Major components include:

- Comminutor (not used because of high maintenance)
- Hand-cleaned bar screen
- 1,000-m3 (264,000-gal) oxidation ditch
- 79.1 m diameter x 30.5 m deep (26 ft x 10 ft) peripheral feed clarifier
- 123.6 m x 123.6 m (40 ft x 40 ft) I/P ponds (2)
- 223-m3 (59,000-gal) aerobic digester
- 76 m x 76 m (25 ft x 56 ft) sludge drying beds (2)

A facultative lagoon was replaced by the mechanical plant; however, because of plugging problems associated with the infiltration/percolation (I/P) ponds, the lagoon was placed back in operation. Effluent from the lagoon discharges to a receiving stream.

A CPE was conducted at the plant because of suspected performance problems. The performance potential graph for the facility is shown in Figure 4-46. The major design limitations include the aerobic digester and the sludge drying beds. These limitations, plus the presence of "Operator Application of Concepts and Testing to Process Control" as a factor limiting performance, had contributed to insufficient sludge wasting and solids loss from the secondary clarifier. Most of these solids had been captured in either the I/P ponds or the facultative lagoon; consequently, plant effluent generally met the discharge standards. However, solids loss was contributing to plugging of the I/P cells, and thus non-disinfected effluent was discharged from the old lagoon. A sludge accountability analysis projected that an annual average effluent TSS of 56 mg/L and BOD_5 of 32 mg/L could have been expected from the secondary clarifier discharge given the existing operational practices.

The CPE results led to initiation of a CCP at the plant. Emphasis was placed on the implementation of a mass control program resulting in routine sludge wasting from the oxidation ditch system. Because of the limitations of the aerobic digester and the sludge drying beds, a land application program had to be developed. The town purchased a 5.7-m^3 (1,500-gal) truck for hauling sludge. Arrangements were made with local farmers to use their land for application of the digested sludge. Preparation for the land application program included evaluation of the sites (e.g., soil, slope, ground water) and testing of the sludge for required parameters (e.g., metals, nitrogen, phosphorus).

Since completion of the CCP, solids loss from the secondary clarifier has been eliminated and the sludge handling limitation has been addressed through the implementation of the land application program. In this study, inaccurate projections of waste sludge production (mass and volume) resulted in significant limitations in sludge handling capabilities.

Even when the correct mass of sludge produced is established, poor estimation of sludge volume can result in severely overloaded treatment processes. For example, poor settling and accompanying poor compaction characteristics often occur in activated sludge processes. These conditions result in the need to waste higher sludge volumes in order to remove the desired mass of sludge. Variability in sludge production (e.g., peak as well as average data) is shown by the following.

Case History: Tuscaloosa, Alabama Wastewater Treatment Plant
The Tuscaloosa wastewater treatment plant is an activated sludge facility with anaerobic digestion. The design flow of the plant is 679.4 L/s (15.5 mgd). The primary treatment portion was built in 1958, along with three anaerobic digesters. The secondary treatment portion and one additional digester was built in 1974. In 1982, a dissolved air flotation unit was constructed to thicken sludge from the activated sludge process prior to introducing the sludge to the anaerobic digesters. Two sludge lagoons, adjacent to the plant, are used for disposal of all solids from the plant. Supernatant from these lagoons is returned to the headworks.

Sludge production data for 1986 are summarized in Figure 4-47 and Table 4-12. Primary, secondary, and total sludge production are shown.

During the year the plant treated an average flow of 539.1 L/s (12.3 mgd), and influent BOD_5 and TSS concentrations averaged 205 mg/L and 161 mg/L, respectively. The average sludge production for the year was about 10,440 kg (23,000 lb)/d. The combined total maximum monthly and weekly sludge production amounts were 11,723 kg (25,820 lb)/d and 12,967 kg (28,561 lb)d, respectively.

The data show that the peak monthly sludge production was 12 percent higher than the average yearly value. The maximum weekly sludge production occurred in December, and was 24 percent higher than the yearly average value.

The peak monthly and weekly sludge production for the primary clarifiers was 30 percent and 54 percent, respectively, higher than the yearly average value. For the activated sludge (secondary) portion of the plant, the peak monthly and weekly sludge production was 27 percent and 46 percent, respectively, higher than the yearly average value.

4.6.1.1.1 Variability Considerations

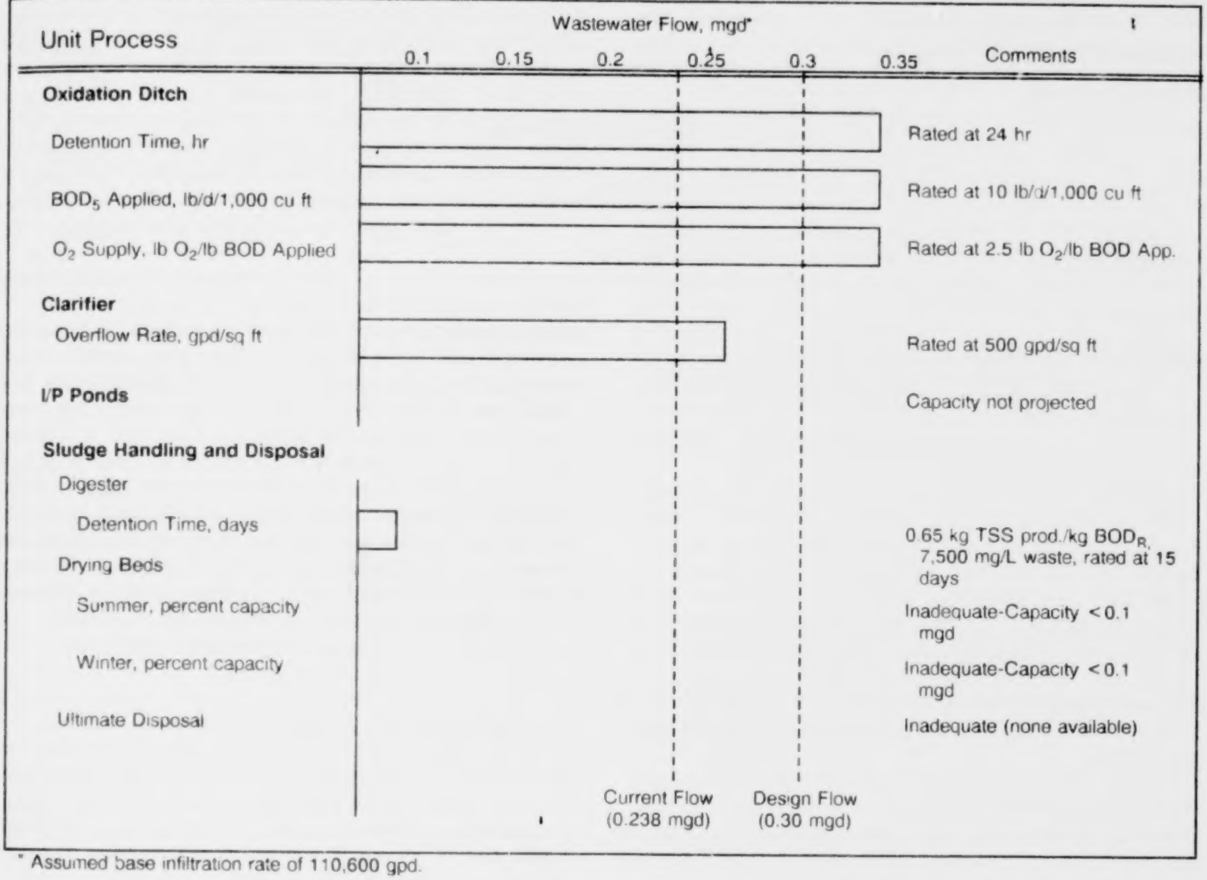
Variability in the mass and volume of sludge produced occurs for a variety of reasons including:

- Normal influent loading variations. Reliable data bases on POTW influent wastewater characteristics give preliminary definition to the variability of primary and/or waste secondary sludge solids. The variability of concentrations of BOD_5 and TSS plus the variability in peak day/period flows must be considered to provide an adequate sludge management system. Table 4-13 summarizes variations for selected periods based on reported minimum and maximum deviations encountered with sustained mass influent loadings for BOD_5 and TSS (49).

- Operational changes (e.g., increased solids processing requirements resulting from reducing system SRT, changes in return sludge flow rates).

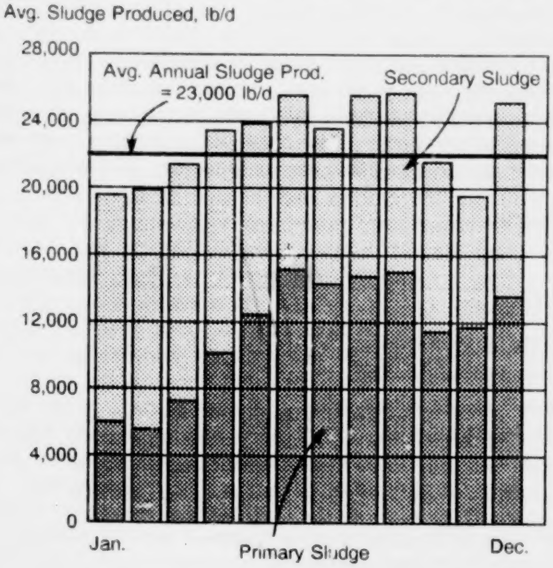
- Normal variations in biological unit process performance (e.g., changes in activated sludge

Figure 4-46. Stevensville, Montana performance potential graph.



* Assumed base infiltration rate of 110,600 gpd.

Figure 4-47. Tuscaloosa, Alabama 1986 sludge production.



settling characteristics, sloughing of solids from fixed film facilities).

- Normal variations in unit process performance (e.g., thickening, dewatering).
- Impact of downtime of sludge processing equipment.
- Impact of climatic factors (e.g., winter performance of sand drying beds, weather impacts on ultimate disposal options).

Because of these factors, variability is *never* eliminated and must be considered in all phases of sludge management system modification design. *Design based on "average" conditions is inadequate.* Good design requires adequate projection of mass, volume (e.g., concentration), and the variability of each of these individual parameters.

4.6.1.1.2 Mass Considerations

Inaccurate projections of the amount of sludge that a process will produce is frequently a limitation that

Table 4-12. Sludge Production Data for Tuscaloosa, Alabama WWTP

Process	Parameter	1986 Data		
		Avg. Year	Max. Month	Max. Week
Primary Clarification	Primary Sludge Produced, lb/d	11752	15,253	18,071
	Ratio of Maximum Period to Average Year	1.00	1.30	1.54
	Unit Sludge Production Ratio, lb solids/lb BOD removed	1.82	2.84	3.12
Secondary (Activated Sludge)	Sludge Produced, lb/d	11,285	14,331	16,310
	Ratio of Maximum Period to Average Year	1.00	1.27	1.46
	Unit Sludge Production Ratio, lb solids/lb BOD removed	0.86	1.01	1.32
Combined Primary/Secondary	Total Sludge Produced, lb/d	23,037	25,820	28,561
	Ratio of Maximum Period to Average Year	1.00	1.12	1.24

Table 4-13. Summary of Reported Minimum and Maximum Variations with a Sustained Mass Loading for Selected Periods (49)

Period	Percent of Average Loading	
	BOD_5	TSS
Daily	15-250	15-270
Weekly	60-160	67-167
15 Days	65-125	75-145
Monthly	75-120	80-125

impacts plant performance. Following are considerations that should be included in sludge mass projections.

Primary Sludge Accumulation

Primary clarifiers are normally assumed to remove between 50 to 70 percent of the influent TSS and 25 to 35 percent of the influent BOD_5. However, these removals are a function of, among others, influent wastewater characteristics, clarifier overflow rates, clarifier depth, and operations variables (e.g., sludge pumping rates and blanket depths).

To adequately project TSS and BOD_5 removals from primary clarifiers, and thus project impact on sludge management system components, requires that minimum and maximum influent mass loading days be considered. For example, from Table 4-13 the primary sludge pumps should be sized to accept between 0.2 to 2.7 times the mass of TSS anticipated on an average day. Typically, capacity to handle this total range of diurnal fluctuation is not required since operational changes in pumping rate and in blanket depth (e.g., in-plant storage) can be used to accommodate a portion of these variations. If no additional intermediate storage facilities are available, solids loading from a primary clarifier to a high rate anaerobic digester (e.g., 15-day hydraulic detention time) could be based on a 15-day sustained loading. From Table 4-13 this would be approximately 145 percent of the long-term average value, based on influent suspended solids loadings.

Secondary System Sludge Production

TSS and BOD_5 not removed by primary clarifiers are treated in secondary facilities. Inaccurate projections of the mass of waste secondary sludge solids produced can have significant impact of a POTW's performance capability. Several approaches to make these projections are discussed.

Actual Data

Use of actual plant data is the most reliable method of developing accurate sludge mass projections. This method requires extensive data and detailed information on the plant's operational practices. Accurate data is required on flow, volumes, and waste concentrations from all unit processes, including recycle streams. This data is necessary over long time periods to allow for assessment of the variability

Table 4-14. Guidelines for Modifying Existing Sludge Handling Facilities

Process/Facilities	Basis for Modification
Waste Sludge Pumping (Primary and/or Secondary)	Maximum Daily Sludge Production
Waste Sludge Thickening (Primary and/or Secondary)	Maximum Daily Sludge Production
Stabilization	Maximum Monthly Sludge Production*
Dewatering	Maximum Weekly Sludge Production
Transportation	Maximum Weekly Sludge Production
Storage	Maximum Sludge Production Rate for Storage Period Being Considered
Utilization/Disposal	Average Annual Sludge Production for Establishing Area Requirements Maximum Sludge Production for Equipment Sizing and Daily Operating Requirements to Allow for Downtime, Weather Conditions, etc. (e.g., Monthly)

* Maximum weekly sludge production if the hydraulic residence time in the stabilization process is 10 days or less.

that occurs. Additionally, extensive awareness of operations is necessary to assure that undocumented effluent solids loss does not exist and that plant storage of sludge, which masks true sludge production, is not occurring. Facilities that have documented a need for modifications to their sludge handling processes, following the steps in this manual, should have this kind of data available. Table 4-12 is an example of a good summary of one year of actual plant sludge production and variability data.

Other Similar Processes
In the absence of information to utilize actual information, data from other similar processes can be used. Tables 2-7 and 2-17 summarize data based on full scale operating facilities for average *total* sludge production rates for a variety of secondary processes.

Sludge Mass Production Variability
Independent of the procedure utilized to project the average secondary system sludge production, variability effects must also be projected. If actual data are not available, variability based on the minimum and maximum sustained loads, as shown in Table 4-13, can be used for estimation purposes. For example, if a dissolved air flotation (DAF) unit is used to thicken waste secondary sludge from a conventionally loaded suspended growth process, this unit should be designed to process the estimated maximum day loading. However, if the waste activated sludge is pumped from the DAF to an aerobic digester (e.g., 20-day hydraulic detention time), the design of the DAF unit could be based on the 20-day sustained loading projections. From Table 4-13 the variability of TSS would be 80 to 130 percent of average and 75 to 120 percent for BOD_5. These values could be applied to the anticipated average secondary system loadings to include the necessary variability projection in the design of facility modifications.

4.6.1.1.3 Concentrations Considerations

Coincident with establishing masses of sludge accumulation, adequate sludge management system design must accurately project sludge stream concentrations and thus volume. Tables 2-8 and 2-17 present typical sludge stream concentrations from a variety of wastewater treatment processes. Values shown can be significantly varied based on plant operational factors. For example, return activated sludge concentrations are functions of sludge settling characteristics, recycle rates, and other operating- and equipment-related parameters. Changes in sludge characteristics, such as the growth of filamentous organisms, can produce significantly lower return sludge concentrations than those listed. Additionally, return sludge concentrations can vary due to changes in diurnal flow rate and/or operational changes in return sludge flow rate.

In addition to variations in concentrations from the mainstream treatment processes, variations occur in the concentrations from sludge management system unit processes. The effect of these variations on other interactive sluge management system processes must be considered.

In many plants with observed sludge management system limitations, operational adjustments (e.g., in-plant storage of solids in suspended growth processes) had been used to compensate for the sludge unit process limitations, at the expense of plant effluent quality. Operational adjustments *significantly* impact sludge concentration and volume projections. Because of the complex interrelationship of unit process capability and operational controls, it is proposed that design proceed by addressing concentration and resulting volume variations on a *worst case* basis, taking the plant's operational flexibility into consideration.

4.6.1.2 Flexibility

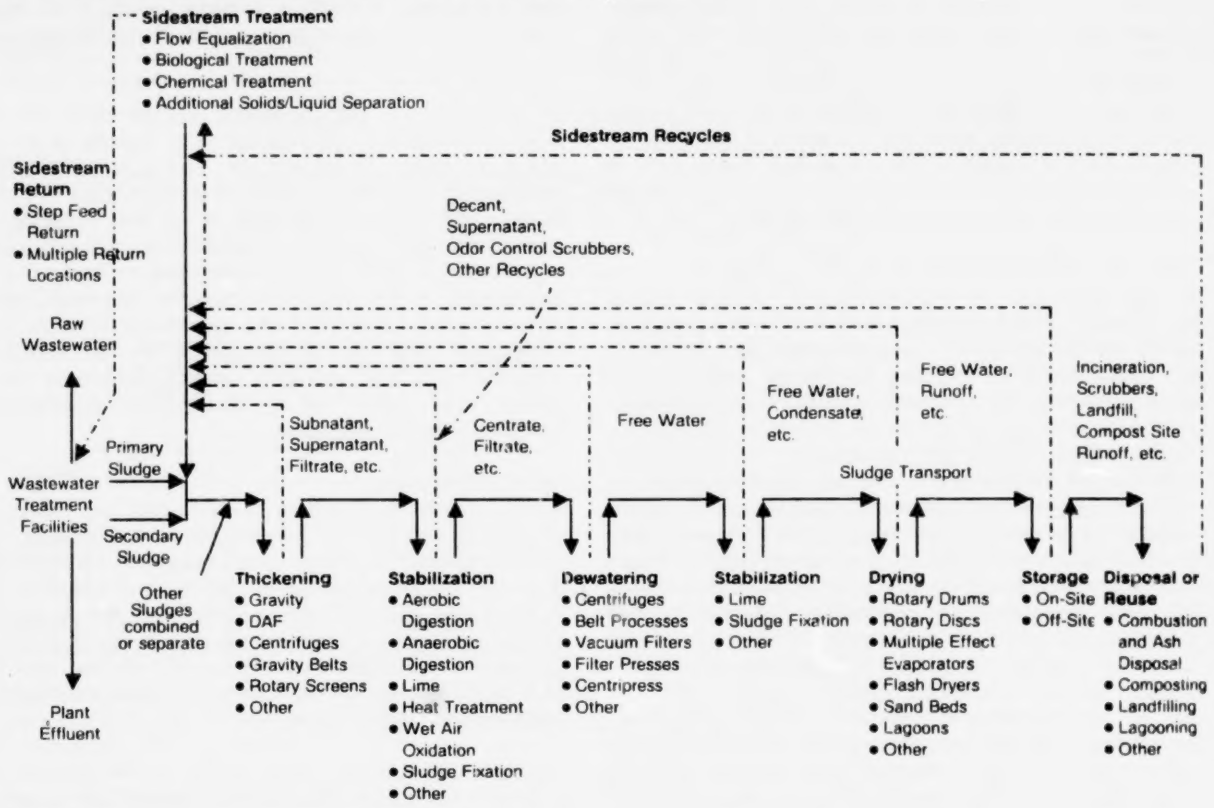
Ideally, adequate flexibility exists when any mass of sludge, as required by the process control strategy for the wastewater treatment processes, can be removed from the treatment process at any time of the year. To achieve this flexibility requires that multiple equipment or operational options be available to the plant operators. Facilities thus equipped will be able to reduce the impact on plant performance attributable to sludge handling deficiencies.

Figure 4-48 illustrates many of the current options for sludge handling facilities. When evaluating modifications to existing sludge handling processes, it is important to be aware of the multiple process options available. Another important aspect of sludge facility modifications is the interelation of processes (e.g., improved thickening can dramatically improve stabilization capabilities and improved stabilization can improve dewatering, etc.). Therefore, the most effective solution for a sludge handling problem may often be the improvement of an adjacent interactive process.

One of the most effective additions to sludge handling capability is storage. Sludge storage can be after stabilization (e.g., second stage digester), after dewatering, or off-site near the disposal/reuse location. Even multiple storage points in the process diagram may be of value. When storage occurs sooner in the process flow diagram, more downstream processes are benefited, however, greater sludge volumes are involved.

To ensure adequate flexibility, facility modifications of sludge treatment and disposal processes should be based on sludge production (e.g., mass, volume, and variability) for the peak design period loading. In the absence of actual operating data, guidelines have been developed and are presented in Table 4-14. Flexibility can be assessed by developing a mass balance schematic for the unit processes to be

Figure 4-48. Typical sludge handling, treatment, and disposal processes (96).


Sidestream Treatment
• Flow Equalization
• Biological Treatment
• Chemical Treatment
• Additional Solids/Liquid Separation
Sidestream Recycles
Sidestream Return
• Step Feed Return
• Multiple Return Locations
Decant, Supernatant, Odor Control Scrubbers, Other Recycles
Raw Wastewater
Wastewater Treatment Facilities
Primary Sludge
Secondary Sludge
Other Sludges combined or separate
Plant Effluent
Subnatant, Supernatant, Filtrate, etc.
Centrate, Filtrate, etc.
Free Water
Free Water, Condensate, etc.
Free Water, Runoff, etc.
Incineration, Scrubbers, Landfill, Compost Site Runoff, etc.
Sludge Transport
Thickening
• Gravity
• DAF
• Centrifuges
• Gravity Belts
• Rotary Screens
• Other
Stabilization
• Aerobic Digestion
• Anaerobic Digestion
• Lime
• Heat Treatment
• Wet Air Oxidation
• Sludge Fixation
• Other
Dewatering
• Centrifuges
• Belt Processes
• Vacuum Filters
• Filter Presses
• Centripress
• Other
Stabilization
• Lime
• Sludge Fixation
• Other
Drying
• Rotary Drums
• Rotary Discs
• Multiple Effect Evaporators
• Flash Dryers
• Sand Beds
• Lagoons
• Other
Storage
• On-Site
• Off-Site
Disposal or Reuse
• Combustion and Ash Disposal
• Composting
• Landfilling
• Lagooning
• Other

incorporated into the plant's design. This schematic can be used to depict the "worst case" scenarios for the operation of the sludge handling processes. Variable values for flow, concentration, and mass can be added for the anticipated worst case operating conditions to "test" the flexibility of the sludge handling capability provided.

4.6.2 Selecting Modification Approaches

Table 4-15 summarizes design/corrective modifications that are prioritized based on their potential for achieving improved performance. Modifications with proven reliability and those that are less construction intensive appear at the beginning of the listing.

4.6.3 Inadequate Sludge Thickening Capability

The flexibility to thicken waste sludge from a treatment process, typically a suspended growth process, provides the following advantages: 1) increased detention time in stabilization processes, 2) increased solids concentration to enhance digestion, and 3) reduced sludge volume to ultimate disposal or beneficial use. Common processes used for thickening include gravity, flotation, and mechanical thickening with centrifuges or presses.

Table 4-15. Sludge Handling Design Limitations and Potential Modifications

Design Limitation/Potential Modification	Page. No.
Thickening	
4.6.3 Inadequate Sludge Thickening Capability	120
4.6.3.1 Chemical Addition to Existing Thickener	121
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In some cases, minor operational or design related changes can be implemented to increase waste sludge concentration. For example, the addition of chemicals to primary or secondary clarifiers can produce thicker sludges. The use of positive displacement pumps will allow thicker sludge withdrawals than non-clog centrifugal types. Treatment plants with dedicated waste sludge pumps can use a time clock with the pump to waste small quantities of sludge several times each day instead of wasting the total volume once per day. Since sludge concentration typically decreases with increasing duration of the pumping cycle, the pump operation can be stopped for a period of time to increase the sludge concentration at suspended growth plants that utilize the same pump for the return and waste sludge functions. Comparing pump "off times" versus corresponding sludge concentrations can be used to optimize this approach. Often waste sludge concentrations of 8,000-15,000 mg/L can be achieved when the pump is off for a period of 15-60 minutes. This procedure may require similar around-the-clock operation of some downstream processes.

4.6.3.1 Chemical Addition to Existing Thickener

Generally, the capacity and solids capture of sludge thickening processes can be increased through the addition of a polyelectrolyte to the sludge stream before the process. The thickened sludge concentration will not typically increase. To determine the feasibility of this modification, it is recommended that jar testing utilizing different polymers be completed. If tests indicate that improved performance is possible, then full-scale polymer addition should be tested before large capital expenditures are made for polymer storage and feed equipment.

The optimum location for polymer addition depends on differences in polymer charge densities, required polymer reaction times, and sludge characteristics. Recommended locations include:

- Directly before the inlet side of the sludge feed pump

- Immediately downstream of the sludge feed pump

- Prior to introduction to the sludge thickening process (59)

Polymer addition to a gravity thickener may allow a solids loading rate increase of two to four times the rate for a unit not receiving polymer (59). Typical polymer dosages are from one to five milligrams per liter (61). In the case of dissolved flotation thickeners, polymers are usually essential to achieve effective co-flocculation of the air bubbles and sludge particles (59). Polymer requirements are usually 2.5-7.5 g polymer/kg dry solids (5-15 lb/ton) (61). Similar polymer dosage rates can be expected when using centrifuges, gravity belts, or rotary drums for thickening.

4.6.3.2 Additional or Alternate Thickening Process

The addition of a sludge thickening process can be used to address a sludge handling limitation. Other sources provide design, operation, and maintenance information on sludge thickening (59,61,62).

When evaluating thickening alternatives, consideration should be given to the following factors:

- Compatibility of the thickening equipment with the existing sludge

- Process flexibility

- Worst case performance conditions.

Often the thickened sludge output concentration given for different thickening processes is optimistic. To provide adequate flexibility, worst case concentration values should be used during design.

If a new process or new application of an existing process is being evaluated, completion of a pilot study is usually advantageous. A pilot study, utilizing existing sludge, can provide valuable information on solids loading rates, solids capture, chemical dosages, and operational requirements. The pilot study should be of sufficient duration to test the proposed system under a variety of sludge conditions. Pilot scale thickening equipment is frequently available from manufacturers.

If centrifuges or other mechanical thickening processes are being evaluated, consideration should be given to providing flexibility to thicken sludge from several sources. For example, with a suspended growth process utilizing aerobic digestion, the thickening equipment could be used to: 1) thicken waste activated sludge prior to digestion, 2) thicken aerobic digester sludge to increase digester solids detention time, or 3) thicken digester sludge prior to disposal or utilization.

4.6.4 Inadequate Sludge Stabilization Capability

Sludge stabilization processes provide: 1) volatile solids reduction, 2) pathogen destruction, and 3) reduction of the odor potential and putrescibility of the sludge. If inadequate sludge stabilization capability exists, problems typically occur with disposal or utilization of the sludge. Secondary treatment process are affected if insufficient sludge can be wasted or if supernatant returned from a digester adversely affects the secondary process.

Before modifying sludge stabilization facilities, operational changes should be investigated:

- Eliminate supernatant return (e.g., apply to agricultural land)

- Pretreat supernatant

- Improve solids capture from thickening or dewatering processes

- Thicken aerobic digester sludge (e.g., add chemical coagulants to the digester, allow settling, and remove supernatant)

4.6.4.1 Improved Thickening/Dewatering

The capacity and performance of sludge stabilization processes can sometimes be improved through additional thickening or dewatering of the feed sludge to the process. With aerobic digestion, additional thickening of the feed sludge will increase the solids residence time in the basins and subsequently the volatile solids reduction. With anaerobic digestion, thickening of primary sludge can usually be regulated through the operation of the primary sludge pumps. However, low concentration sludge from a suspended growth process can sometimes have a negative impact on the optimum temperature of the anaerobic digestion process. Under these circumstances, it is advantageous to direct the secondary sludge to a thickening process prior to anaerobic digestion. Other stabilization processes, such as composting, require a dry sludge cake to optimize the process performance. Information on sludge thickening is presented in Section 4.6.2.

4.6.4.2 Additional Blowers or Diffuser Replacement (Aerobic Digestion)

The aerobic digestion process requires 1.7-3.7 kg of oxygen to oxidize 1 kg of cell mass (59,63). If inadequate oxygen supply is available volatile solids reduction will not be optimized. The addition of blowers or the replacement of existing diffusers can provide increased oxygen as discussed in Section 4.4.4. When considering diffuser replacement, the impact of diffuser fouling should be carefully evaluated. Diffuser fouling potential is greater in aerobic digesters because of high sludge concentrations, accumulation of rags, and the practice of stopping the aeration equipment during periods of digester settling and supernatant removal. Fine bubble ceramic diffusers are least suitable in this application because the actual oxygen transfer values are found to be so low in the high solids environment that the diffusers are not cost effective.

4.6.4.3 Lime Stabilization

Lime addition to sludge reduces odors and pathogens by the creation of a high pH environment that limits biological activity. Lime addition also affects the chemical and physical characteristics of sludge. Changes include reduced fertilizer value, improved dewaterability, and changes in the character of liquid sidestreams. Parameters used in sizing lime stabilization facilities include: pH, contact time, and lime dosage. The process objective is to maintain the sludge at a pH above 12 for about two hours to ensure pathogen destruction and to provide sufficient residual alkalinity to maintain the pH above 11 for several days to allow time for reuse or disposal without renewed biological activity (59). Experience has shown that lime dosages of 10-50 percent of the total dry solids in the sludge are required to achieve the conditions described above.

Lime stabilization is a relatively simple process to implement; consequently, it may be applicable as a backup process for existing stabilization facilities or as an interim sludge handling process. Disadvantages of this process include high chemical and labor requirements and a substantial increase in the amount of dry solids that require disposal. Design information can be found in other sources (59).

4.6.4.4 Additional Heat Exchanger Capacity For Anaerobic Digesters

Thickening of the feed sludge can be used to reduce heating requirements for anaerobic digesters. This option should be investigated before major modifications are made. The capacity of anaerobic digesters can be increased by replacing an existing heat exchanger or adding a new heat exchanger to a non-heated or under-heated digester. Heating is an important component of the anaerobic digestion process. By increasing the temperature of the digesting sludge, the metabolic rate is increased and the required digestion time is reduced. Temperature control is also important. To achieve process stability, the temperature of the digester contents is maintained within ±0.56°C (1°F).

The most common heating method is the use of external heat exchangers. Three common types include: water bath, jacketed pipe, and spiral (59). Design information on these systems can be found in other sources (2,59).

4.6.4.5 Improved Mixing Capability

Adding mixing capability to a non-mixed anaerobic digester will improve process stability and increase digester capacity. Replacing existing mixing equipment with more effective mixing equipment may also improve process stability or increase capacity. Mixing benefits include: 1) distribution of the feed sludge with the active biomass; 2) consistent physical, chemical, and biological conditions; 3) rapid dispersion of any toxic materials, thus minimizing their effect on microbial activity; 4) uniform temperature; and 5) minimization of sand, grit, and scum accumulation (59).

Methods used for mixing include external pumped circulation, internal mechanical mixing, internal gas mixing, and direct steam injection. Design information can be found in other sources (2,59).

4.6.4.6 Additional or Alternate Stabilization Process

Where major sludge stabilization limitations exist, either lime stabilization of a portion of the sludge flow should be considered or additional processes must be added. Discussion of commonly used stabilization processes can be found in other sources (2,57).

4.6.5 Inadequate Sludge Dewatering Capability

The objective of dewatering is the removal of water and thus volume from stabilized sludge prior to reuse or ultimate disposal. A secondary objective is to minimize the quantity of solids recycled to the main process in the filtrates or centrates. The process reduces the subsequent cost of sludge transportation and disposal. The desired percent solids content of dewatered sludge is established by the disposal or reuse requirements. Inadequate sludge dewatering occurs if throughput from existing equipment exceeds capacity, or if the solids content of dewatered sludge is less than the requirement for disposal or reuse. Inadequate dewatering capability can limit the performance of a secondary treatment process if it inhibits sludge wasting.

4.6.5.1 Additional or Alternate Dewatering Process

Dewatering alternatives include air drying and mechanical processes. Air drying processes include conventional sand beds, paved beds, reed beds, sludge lagoons, vacuum-assisted beds, wedgewire beds, and several other emerging technologies. Mechanical dewatering processes include belt filter presses, centrifuges, filter presses, vacuum filters, and some emerging technologies. Specific information on these various processes is summarized in recent EPA publications (62,81).

4.6.6 Sidestream Return to Wastewater

With nearly all types of sludge handling processes, a sidestream flow, such as supernatant from a digester, is produced that is typically returned to the treatment plant for processing. These sidestreams are typically low in volume when compared to the plant flow; however, they can contain high concentrations of solids, organics, and other compounds, such as nitrogen and phosphorus, which can exert an oxygen demand on the system. A design limitation exists when the sidestream flow produces a negative effect on the secondary process. Sidestreams that can potentially be returned but often are overlooked are: odor scrubbers, incineration scrubbers, collected landfill leachate, free water from storage facilities, and stormwater runoff from sludge compost sites.

Before major modifications are planned, operations-related solutions should be investigated. Changing the operational strategy for anaerobic digesters can result in an improvement in supernatant quality. Possible control strategies include: 1) controlled release of supernatant at night or over a 24-hour period, 2) shutdown of mixing equipment for quiescent decantation, and 3) two-stage operation with supernatant from the second stage. Also, where and how the flows are returned and distributed in the plant can have a major impact on operations. Properly distributed recycles can help to minimize impacts.

Filtrate quality from sludge presses can sometimes be improved by changing the sludge conditioning or operation of the dewatering equipment (e.g., type of chemical, dose, sludge feed rate, roller compression, etc.). Off-site disposal of sidestreams should also be investigated although it may not always be feasible because of site limitations and regulatory requirements.

4.6.6.1 Pretreatment

Pretreatment can be effective in reducing sidestream strength; however, the practice is not common because of the additional operational requirements and cost. Possible pretreatment alternatives include fixed-film and suspended growth processes. Chemical coagulation and sedimentation may also provide additional liquid/solids separation. (See Sections 4.3 and 4.4.)

The return of sidestreams to a flow equalization basin can be effective in diluting waste strength. Consideration should be given to: 1) odor potential, 2) equalization basin volume needed for storage of the sidestream flow, 3) basin aeration requirements, 4) basin mixing requirements, 5) wash down facilities, and 6) solids collection and removal equipment.

4.6.7 Inadequate Sludge Storage Capability

Sludge storage facilities provide the flexibility to retain stabilized sludge in a contained basin or pond for an extended period of time, typically during periods when access to a disposal or reuse alternatives is not possible. The case history that was presented in Section 4.6.1 discussed the variability in sludge production that occurs throughout a typical year. This variability requires that sludge handling facilities, including storage facilities, be sized to handle peak loads (periods of down time, bad weather, seasons, etc.).

A common practice in plants that have sludge handling limitations is to increase the sludge inventory in the secondary process as a means of storing excess solids. Although sometimes effective on a short-term basis, this practice can have negative effects on sludge settling characteristics and eventually system performance.

Another common practice for increasing sludge storage capacity in a treatment plant is the removal of supernatant from digesters. The development of supernatant in digesters can sometimes be enhanced by the addition of a coagulant. Portable submersible pumps have been successfully used to enhance supernatant removal in aerobic digesters.

4.6.7.1 Mechanical Thickening

Mechanical thickening can be an effective means of increasing the detention time of solids in an aerobic digester or storage basin. If conventional gravity thickening is practiced, the solids concentration of sludge in these units is limited to two to three percent by weight. By mechanically thickening the contents of the digester/storage basin, this concentration can be increased to four to six percent by weight. This modification may be limited by the aeration capacity of the aerobic digester. Section 4.6.3 provides equipment and information references.

4.6.7.2 Additional or Alternate Storage Facilities

Various alternatives are available for the storage of liquid, thickened, and dewatered sludges. The most appropriate alternative will be dependent on the existing sludge handling limitations, the eventual use for the sludge, the length of time that storage is required, and the available resources (i.e., land, existing basins).

Where land application is the ultimate disposal method, the application may be halted for long periods due to weather conditions. In this case, storage facilities for stabilized sludge significantly increase the flexibility of this practice. Information on design considerations for sludge storage facilities can be found in *Design Manual on Sludge Treatment and Disposal* (59).

4.6.8 Inadequate Sludge Transportation Capability

The relocation of wastewater sludge to the disposal or reuse site requires some method of transportation. Conventional transportation methods include trucks and pipelines. This limitation should rarely affect the performance of secondary treatment processes since contract haulers and/or leasing options are typically available. Additional information can be found in *Design Manual on Sludge Treatment and Disposal* (59).

4.6.9 Inadequate Sludge Utilization/Disposal Capability

Wastewater sludge is disposed of through such means as landfilling or for soil conditioning and fertilization. Inadequate utilization or disposal facilities can have a major effect on secondary treatment process performance. As such, it is essential to have several alternatives available.

4.6.9.1 Additional or Alternate Sludge Utilization/Disposal Facilities

The development of additional or alternate sludge utilization/disposal facilities is one of the most effective methods of providing plant flexibility. Numerous alternatives are available. Often development of alternatives does not require large capital expenditures but does require planning, coordination, and public relations. Specific information can be found in other sources (59,64,65).

4.7 Additional Facility Modifications

This section discusses performance-related facility modifications not covered previously. Included are modifications of the disinfection system, the wastewater stream, and emergency or non-routine operational procedures. Commonly identified design limitations associated with these categories are presented in Table 4-16.

Table 4-16. Additional Design Limitations

Design Limitation/Potential Modification	Page. No.
Disinfection Systems	
4.7.1.1 Modifications to Chlorine Disinfection Systems	125
- Short-Circuiting	
- Inadequate Contact Time	
- Inadequate Chlorine Feed Capacity	
- Inadequate Mixing	
4.7.1.2 Modifications to Ozone Disinfection Systems	127
- Inadequate Ozone Transfer Efficiency	
- Inadequate Feed Gas Preparation	
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- Inadequate Contact Time	
4.7.1.3 UV Radiation Disinfection Systems	128
- Inadequate Cleaning System	
- Short-Circuiting	
Miscellaneous Systems	
4.7.2.1 Modifications to Wastewater Characteristics	129
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Emergency Systems	
4.7.3.1 Modifications to Respond to Non-Routine Operation	130
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4.7.1 Disinfection System Modifications

Disinfection is used to destroy or inactivate pathogenic (disease-causing) microorganisms in a treatment plant's effluent. Chlorine, ozone, and ultraviolet radiation have been the primary disinfectants used to accomplish this task. Before modifications are proposed, the performance of upstream processes should be optimized operationally to ensure that the highest quality effluent is being achieved prior to disinfection. Modifications to upstream processes to improve disinfection performance are generally not cost effective unless effluent BOD_5 and TSS standards are also being violated.

Operational efforts to reduce organic compounds and SS can improve disinfection performance. Organic compounds and ammonia exert a chlorine demand; consequently, chlorine dosage to an effluent with significant quantities of these constituents must be higher to achieve desired bacterial kill. SS impact chlorine efficiency by sheltering the bacteria from the chlorine. Wastewater quality affects ozone transfer efficiency and thus the performance of existing contact basins. SS also inhibit the effectiveness of ozone disinfection. SS affect performance of UV systems to a greater extent than either chlorine or ozone systems. Chlorine and ozone can penetrate solid particles to provide disinfection. However, UV radiation must make direct contact with the microorganism to inactivate it. Suspended solids will deflect UV radiation, thereby protecting entrapped microorganisms. Organic and inorganic compounds in the wastewater absorb UV energy, reducing the intensity of the radiation, and thus disinfection capability.

Facility modifications directed toward improving the efficiency of disinfection processes are presented in the following sections.

4.7.1.1 Chlorine Disinfection Systems

Chlorine disinfection systems maintain a chlorine residual in the wastewater for an extended period of time. Design-related factors that can impact the effectiveness of the process include: short-circuiting, initial mixing of chlorine with wastewater, applied chlorine dosage, and length of contact time.

a. Short-Circuiting

Short-circuiting most often can cause poor disinfection efficiency, as illustrated in Table 4-17. As shown, a minimal amount of short-circuiting has a significant impact on disinfection efficiency.

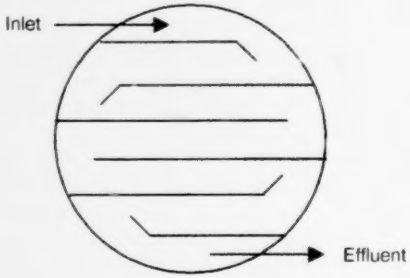
Table 4-17. Effect of Short-Circuiting on Disinfection Performance (67)

Influent Coliform (#/100 mL)	Effluent Coliform Target (#/100 mL)	Short-Circuiting (%)	Resulting Effluent Coliform (#/100 mL)
100,000	200	0.00	200
100,000	200	0.10	300
100,000	200	1.00	1,200
100,000	200	2.00	2,200

If short-circuiting is suspected, it is recommended that a dye tracer study of the contact basin be conducted. Such a study provides data to evaluate the extent of short-circuiting, such as the effectiveness of initial mixing, and the ratio of actual to theoretical contact time (66). Ideally, the contact basin should exhibit plug flow characteristics (e.g., no wastewater passes through the basin in less than the theoretical detention time). The best method of approximating plug flow is to use a long, full-flowing pipeline as the chlorine contact unit. This may be possible at plants that have an outfall sewer line with a sufficiently long time of travel. Otherwise, the chlorine contact basin can be modified to approximate plug flow with the addition of baffles and deflecting vanes.

Occasionally, an existing circular basin (i.e, abandoned clarifier) will be used as a chlorine contact basin. If the basin isn't baffled, serious short-circuiting will occur. Figure 4-49 illustrates a method for baffling a circular basin. The angled extensions at the end of some of the baffles provide for more efficient use of the tank volume.

Figure 4-49. Addition of baffles to existing circular contact basin.



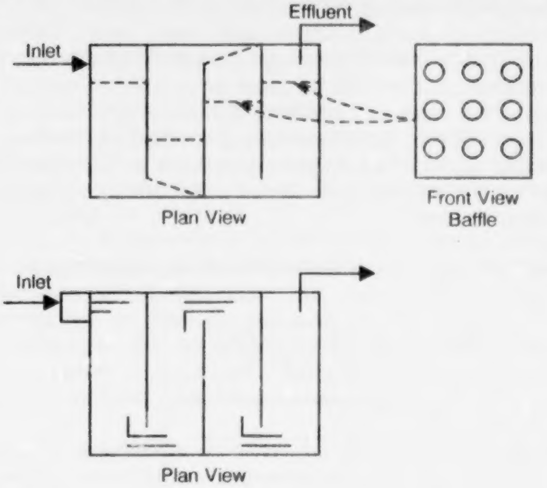
Some older rectangular contact basin designs utilized a cross-baffled configuration. This configuration is not as efficient as a longitudinal configuration because the cross-baffled layout usually has more turns for a given length to width ratio (68). Two potential modifications to a cross-baffled basin are shown in Figure 4-50. The first modification involves the installation of diffusion-wall baffles near the inlet, outlet, and at the turns. The second modification involves the installation of turning vanes. Both approaches have proved effective in increasing the efficiency of cross-baffled contact basins (68).

b. Initial Mixing of Chlorine With Wastewater

The initial mix of chlorine with wastewater should be very rapid and thorough to ensure that all pathogens are brought into close contact with the disinfectant. This is the most important factor affecting chlorine disinfection efficiency. This initial mixing should be completed 5-15 seconds after chlorine comes in contact with the wastewater (66). Common mixing systems include: in-line diffuser, mechanical mixer, hydraulic jump, and jet mixer. This is the most important factor affecting chlorine disinfection efficiency.

To improve mixing for systems utilizing in-line diffusers, relocation of the diffuser to a location with more turbulence can sometimes be effective. In cases where a pump is used to transport secondary clarifier effluent to a contact chamber, chlorine can be added prior to the pump suction. If typical chlorine dosages are used (i.e., 2-10 mg/L), damage to the pump

Figure 4-50. Modifications for cross-baffled contact basins.



impeller due to reaction with the chlorine should not be a problem. For cases where the clarifier effluent flows by gravity through pipes and channels to the contact chamber, potential sites for a chlorine diffuser include transition points (e.g., change from channel to pipe), flow measurement stations (e.g., Parshall flume), and locations where a sudden change occurs in grade. The following case history presents an example of diffusion relocation.

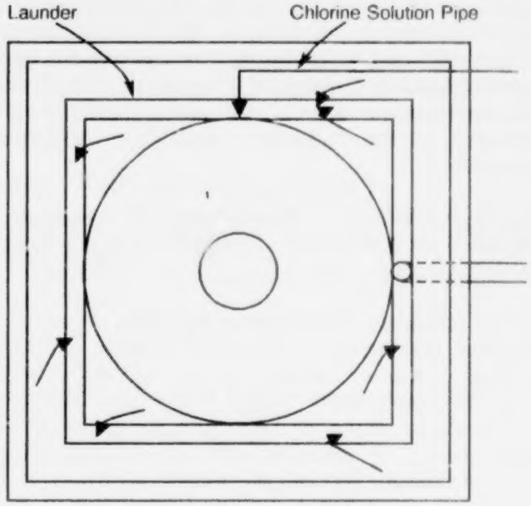
Case History: Modification of the Chlorine Feed Point at the Great Falls, Montana Wastewater Treatment Plant (69)

The Great Falls wastewater treatment plant has two chlorine contact basins with a combined volume of 2,460 m^3 (650,000 gal). In 1981, the plant was treating an average dry weather flow of about 438 L/s (10 mgd), and flow during the day varied from 131 to 789 L/s (3-18 mgd). The theoretical basin contact time at the peak flow of 789 L/s (18 mgd) was 52 minutes. Dye studies indicated that a large portion of the dye was leaving the basins in less than 30 minutes.

The discharge permit for the plant included a 200 fecal coliforms/100 mL monthly average limit and a maximum chlorine residual limit of 0.5 mg/L. Since dechlorination facilities were not available, the staff were required to balance the chlorine feed rate to achieve the desired bacterial kill while not exceeding the maximum residual chlorine concentration. The plant was consistently exceeding their coliform permit limit.

In an effort to reduce short-circuiting, four redwood baffles were installed, thereby creating an over-under flow pattern. The effluent fecal coliform count decreased but was still higher than the permit limit. A modification was implemented to introduce chlorine solution into the wastewater flow stream before it entered the clarifier effluent launders. The modification, shown in Figure 4-51, consisted of 1/2-in flexible PVC tubing which was attached to the clarifiers' scum baffle below the water level. 1/16-inch holes were drilled into the tubing at 30-cm (12-in) intervals.

Figure 4-51. Plan view of secondary clarifier with chlorine solution diffuser.



Following the installation of the modification, a 50 percent increase in the chlorine feed rate was required to meet the fecal coliform limit; however, the residual chlorine limit was achieved. Table 4-18 summarizes fecal coliform counts and chlorine residual concentrations before and after the modification. The presence of chlorine in the clarifier effluent has significantly limited the growth of algae on the launders and walls; consequently, the amount of time required for clarifier housekeeping has been reduced.

Direct injection of chlorine gas into wastewater is an alternative approach to the conventional technique of injecting strong aqueous chlorine solutions. The direct gaseous injection technique, referred to as jet disinfection, has been reputed to provide superior bacterial kills per pound of chlorine at reduced detention times. Such qualities would make jet disinfection a good candidate for retrofitting a chlorine disinfection process that has either poor initial mixing, inadequate contact time, or insufficient dosage capabilities. However, results from studies by independent investigators did not substantiate these claims (70,71). Onsite pilot testing of such a process is recommended before a full-scale installation is pursued.

c. Applied Chlorine Dosage

Typically, the chlorine dosage required to disinfect secondary treatment plant effluents ranges from 2 to 10 mg/L (72). The required dosage will vary

Table 4-18. Fecal Coliform Counts Before and After Installation of Diffuser

Month	Geometric Fecal Coliform Mean (#/100 mL)	Average Cl_2 Residual (mg/L)
April 1978	800	0.3
May	2,000	0.2
June	11,600	0.2
July	11,700	0.2
August	6,100	0.2
September	174,000	0.2
October	2,300	0.2
November	46,000	0.2
December[1]	511	0.3
January 1979	1,000	0.3
February	83	0.3
March	63	0.3
April	32	0.3
May[2]	282	0.3
June	58	0.4
July	175	0.3
August	138	0.3
September	147	0.3
October	28	0.3
November	26	0.3
December	34	0.3

[1] Installation of diffuser rings completed in December 1978.

[2] During May 1979 the ring diffusers were taken out of service for maintenance, resulting in high coliform counts on two days.

depending on water quality, mixing conditions, temperature, pH, contact time, and the level of disinfection required. Additional feed capability can be added by increasing the capacity of the chlorine delivery system (e.g., chlorine regulators, evaporators). Depending on the size of the existing regulator, the capacity of an existing system can sometimes be increased by exchanging rotometers. The equipment supplier can provide information on the expandability of existing chlorine feed equipment. The potential for increasing the chlorine feed rate is sometimes limited due to residual chlorine discharge standards. In these situations, the installation of a dechlorination system may be required. Recent regulatory changes are also increasing the need for dechlorination capability at treatment plants.

d. Length of Contact Time

Modifications that address short-circuiting are intended to make the actual contact time nearly equal to the theoretical contact time. However, these measures may not be sufficient at treatment plants where the theoretical contact time is too short. As a general guideline, the wastewater should be in contact with the chlorine residual for at least 15 and preferably 30 minutes at peak flow. The most direct method of increasing contact time is to enlarge the basin. If this modification is pursued, the expansion should be in terms of the length of the flow path rather than channel depth or width. Design information can be found in other sources (66,68,72).

4.7.1.2 Ozone Disinfection Systems

Ozone disinfection systems perform by maintaining a disinfectant residual in the wastewater over a given period of time. Performance-limiting factors include: inadequate ozone transfer efficiency, inadequate feed gas preparation, short-circuiting, and inadequate contact time.

a. Inadequate Ozone Transfer Efficiency

Factors that affect transfer efficiency include location and type of diffusers, depth of contactor, applied ozone dosage, and water quality (66). A summary of important design considerations related to diffusers is listed below:

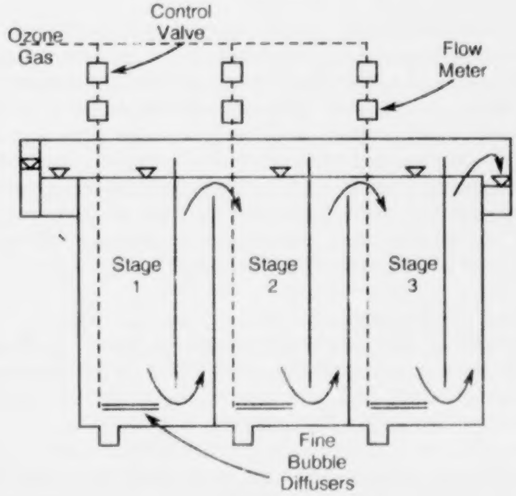
- Diffusers should be at least 4.9 m (16 ft) deep for systems located near sea level, and deeper at higher plant elevations.

- All diffusers should be installed at the same elevation to ensure an even gas flow distribution to each diffuser.

- Gas flow rates should be 0.24-1.18 L/s (0.5-2.5 cfm)/diffuser. High gas flow rates may result in coarse bubbles; low flow rates may result in unequal gas flow distribution.

- Diffusers should be located in the wastewater's downflow stages of the contactor to maximize transfer efficiency. Figure 4-52 shows an ozone contactor utilizing this configuration.

Figure 4-52. Schematic of a 3-stage ozone contact basin (66).



- More diffusers should be located in the first stage than in subsequent stages to satisfy the initial ozone demand of the wastewater. For example, a three-stage contactor may contain 50 percent of the diffusers in the first stage (66).

In many cases, the above conditions can be met by relocating and redistributing diffusers within an existing contactor. Gas flow rates outside the recommended range can generally be corrected by adding or plugging off diffusers. When doing so, the existing diffusers should be inspected for defects and replaced as necessary. New diffusers should be identical to those being replaced to maintain equal gas flow distribution. If the maximum water depth above the diffusers is less than 4.9 m (16 ft), modifications to the ozone generator capacity or contactor may be required. Increasing the depth of an existing contactor is typically not cost effective; consequently, if this approach is being considered, a new contactor should be investigated.

b. Inadequate Feed-Gas Preparation
If either air or recycled oxygen is used as feed-gas for the ozone generator, considerable attention should be paid to the feed-gas preparation system. The two parameters of most concern are the dew point temperature and the particulate content of the feed-gas. The dew point temperature, which is a measure of the feed-gas moisture content, should never be higher than -50°C (-58°F), and should generally be less than -60°C (-76°F) to maximize ozone generator output. An inability to maintain the dew point temperature below these values is an indication of needed modifications to the dessicant dryer process. If existing towers can hold additional dessicant, they should be topped off. Otherwise, it will be necessary to provide additional towers.

Post-dessicant filters should be capable of removing particulates less than 0.3-0.4 microns in diameter from the feed-gas in order to optimize generator production efficiency. To achieve this degree of removal may require two-stage filtration. The first stage filter should remove particulates greater than 1 micron, and the second stage filter should remove particulates greater than 0.3-0.4 microns. Further details on these and other modifications is described in *Design Manual: Municipal Wastewater Disinfection* (66).

c. Short-Circuiting
Poor disinfection has been noted at some facilities due to excessive short-circuiting (66). Short-circuiting has the potential of being a serious problem in many ozone contactors for the following reasons:

- Extensive mixing and backflow occurs in every stage of an ozone contactor due to continuous diffusion of gas into the wastewater. This feature makes it difficult to approximate plug flow.

- Contactors are often designed with an inadequate number of positively isolated stages. The optimum number of stages for a contactor is not known; however, it is recommended that, at a minimum, three stages be provided.

- The hydraulic detention time in an ozone contactor is relatively short, approximately one-third that of a chlorine contact basin, which compounds the impact of short-circuiting.

It is often possible to increase the number of stages within an existing ozone contactor by rearranging the internal baffles and adding new ones. The newly installed baffles should be made of either stainless steel or fiberglass and should provide a serpentine flow pattern that directs downward flow toward the diffusers. Changing the staging in a contactor will also necessitate rearrangement of the diffusers. To minimize short-circuiting between stages, any drain holes in the baffles between the stages should be closed off and replaced with individual drain pits in each stage.

d. Inadequate Contact Time
To reduce the fecal coliform density to 200 per 100 mL, the minimum liquid contact time should be six minutes, and preferably at least ten minutes at design flow rates (66). In most cases, ozone contactors are designed with theoretical contact times greater than these values.

4.7.1.3 Ultraviolet (UV) Radiation Disinfection Systems

UV disinfection systems inactivate bacteria by damaging their genetic code with ultraviolet radiation, thereby preventing replication. Two basic reactor designs are currently used for UV disinfection systems. In the first design, the lamps are encased in quartz sleeves which are submerged in the wastewater at all times (i.e. quartz system). In the second design, wastewater flows through teflon tubes, and the lamps are located outside and parallel to the teflon tubes (i.e., teflon system). Inadequate maintenance and cleaning can reduce UV system performance. UV tubes and lamps must be cleaned frequently and lamps replaced on a regular basis to maintain a high level of radiation intensity transferred to the liquid.

a. Inadequate Cleaning System
If a UV system was installed without an adequate cleaning system, one should be provided. Cleaning is generally accomplished by either mechanical or chemical systems or a combination of the two. Teflon systems can be modified for cleaning by adding a high pressure nozzle system.

At the Rock Springs, Wyoming wastewater treatment plant, a high-pressure nozzle system was able to remove significant portions of the fouling material from the inside surface of the teflon tubes; however, the degree of cleaning was not the same for all tubes. At the Chinook, Montana wastewater treatment plant, the high-pressure nozzle system was effective in removing almost all of the fouling material from the tubes (66,73). These results indicate that, even with a high-pressure cleaning system, internal swabbing of teflon tubes with a soft rag and detergent will occassionally be necessary.

For quartz UV systems, either mechanical wipers or ultrasonics can be provided as adjuncts to chemical cleaning. Wipers appear to have greater potential for maintaining quartz surfaces clean than do ultrasonics. To facilitate chemical cleaning, a recirculation system can be installed to pump a cleaning solution through the UV disinfection unit. Additional information on cleaning UV disinfection systems can be found in other sources (66,73,74).

b. Short-Circuiting

Maximum use of the reactor volume is of great importance in UV systems. A system that does not provide the desired level of disinfection may have significant dead zones or short-circuited areas. These conditions can be identified by analyzing data from dye tracer studies. The manner in which wastewater enters and exits the reactor or channel strongly influences the effective volume (66,73). With proper design, the velocity should be equivalent at all points upon entering and exiting. These conditions can be ensured by installing weirs or perforated baffle plates at the inlet and outlet. Figure 4-53 illustrates the use of weirs and baffles for distributing the flow evenly through UV reactors. Additional information can be found in other sources (66,73,74).

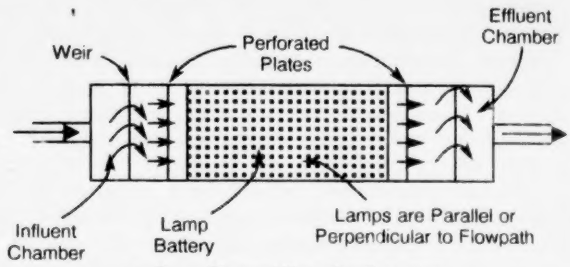
4.7.2 Modifications Directed Toward the Wastewater Stream

There are several physical modifications that can be made at a wastewater treatment plant that do not pertain to a particular unit process (e.g., modification of wastewater characteristics and analytical and process instrumentation).

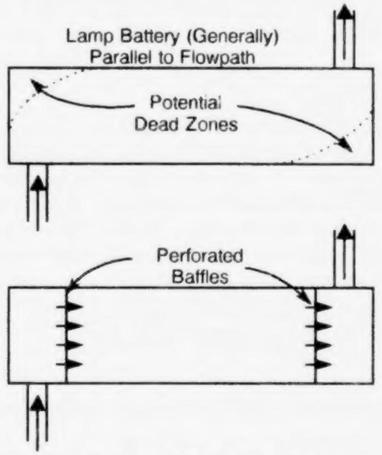
4.7.2.1 Modifications to Wastewater Characteristics

Treatment plants that receive a significant fraction of their wastewater from industrial sources may experience problems with biological treatability. In most cases, the preferred remedy is implementation and enforcement of an industrial pretreatment program that can help to prevent pH extremes, toxic compounds, and compounds resistant to biological degradation from entering the POTW. In some cases, it may be necessary to modify the composition of the wastewater at the POTW. This may involve adding caustic or acid to adjust the pH or adding a coagulation process to precipitate heavy metals. Before implementing any of these approaches, pilot-scale studies should be performed to obtain design information and to establish reliability of the process.

Figure 4-53. Inlet and outlet considerations for quartz UV systems (66).



a. Open Channel Type Configuration



b. Sealed Cylindrical Reactor Configuration

4.7.2.2 Modifications to Provide Instrumentation

To gain an added measure of control over the treatment process, many plants have installed various types of in-basin analytical instruments that allow for remote monitoring. Commonly used measurements include pH, chlorine residual, dissolved oxygen, and suspended solids. Considering the fact that this type of instrumentation is on continuous duty in a relatively unforgiving environment, many of these instruments are prone to fouling and failure. If the instruments require excessive recalibration to maintain a level of reliability, many of the benefits are lost.

In general, remote monitoring systems for chlorine residual are fairly reliable as are some pH monitoring systems. Systems for continuous in-basin monitoring of dissolved oxygen and suspended solids do not have as good a performance record, though there have been successful applications (67). If any of these systems are to be installed, full-scale trial runs should be conducted using instruments from several different manufacturers. A review of considerations for selecting and using in-line analytical instruments is contained in *Wastewater Treatment Plant Instrumentation Handbook* (75).

Another facility modification designed to optimize operator time and improve performance is the installation of programmable controllers. These devices automatically control such parameters as operating sequences, operating speeds, and on-off times of mechanical equipment. A time clock is an example of a simple programmable controller. More advanced controllers regulate the equipment based on analog signals that provide feedback on a given condition. An example of this would be a programmable controller that regulates pumping on-off times based on wastewater levels in a wet well. Programmable controllers generally perform reliably and give the POTW an added measure of controllability.

4.7.3 Modifications Directed Toward Non-Routine or Emergency Operation

It is necessary to provide operational flexibility that allows for continued compliance during and after periods of non-routine and emergency operation. A facility that otherwise has adequate treatment capacity may periodically experience permit violations due to such events as power outages or equipment downtime for maintenance purposes.

4.7.3.1 Modifications to Respond to Non-Routine Operation

Flexibility in the form of unit process bypasses and standby equipment is recommended for every major unit process. A general guideline is to provide a firm capacity for equipment such that, with any given piece of equipment out of service, full capacity is still available. For those processes not provided with standby equipment, critical spare parts should be either kept on-hand or readily available. Such provisions will allow for minimal disruption in plant performance due to equipment downtime.

4.7.3.2 Modifications to Respond to Emergency Conditions

In terms of emergency operation, installation of an alarm system that indicates equipment failures and other abnormal conditions is recommended. The alarm system should include an automatic dialer that notifies someone in responsible charge when critical components fail. For plants that have a history of frequent power outages, a backup power generator may be needed. If the duration of power outages is not significant, a more economical approach for facilities that experience only occasional outages would be auto-restart devices that enable a piece of equipment to automatically resume operation once power is regained.

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When an NTIS number is cited in a reference, that reference is available from:

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
(703) 487-4650

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Appendix A

CPE Classification System, Factors Checklist, and Definitions for Assessing Performance-Limiting Factors

Classification System for Prioritizing Performance-Limiting Factors*

Rating	Adverse Effect of Factor on Plant Performance
A	Major effect on a long-term repetitive basis
B	Minimum effect on a routine basis or major effect on a periodic basis
C	Minor effect
NR	No Rating - factor has no adverse effect on plant performance (i.e., satisfactory assessment of this potentially performance-limiting item)

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* Factors are assessed based on their adverse effect on achieving desired effluent quality.

Checklist of Performance-Limiting Factors

Factor	Rating*	Comments
A. Administration	xxxxx	
1. Plant Administrators	xxxxx	
a. Policies		
b. Familiarity with Plant Needs		
c. Supervision		
d. Planning		
2. Plant Staff	xxxxx	
a. Manpower	xxxxx	
1) Number		
2) Plant Coverage		
3) Workload Distribution		
4) Personnel Turnover		
b. Morale	xxxxx	
1) Motivation		
2) Pay		
3) Work Environment		
4) Working Conditions		
c. Staff Qualification 1) Aptitude 2) Level of Education 3) Certification		
d. Productivity		
3. Financial	xxxxx	
a. Insufficient Funding		
b. Unnecessary Expenditures		
c. Bond Indebtedness		

* A - Major effect on a long-term repetitive basis.
B - Minimum effect on a routine basis or major effect on a periodic basis.
C - Minor effect.
NR - No rating.

Checklist of Performance-Limiting Factors (continued)

Factor	Rating*	Comments
B. Maintenance	xxxxx	
1. Preventive	xxxxx	
a. Effective/Formal Program		
b. Spare Parts Inventory		
2. Corrective	xxxxx	
a. Procedures		
b. Critical Parts Procurement		
3. General	xxxxx	
a. Housekeeping		
b. References Available		
c. Staff Expertise		
d. Technical Guidance (Maintenance)		
e. Equipment Age		
C. Design	xxxxx	
1. Plant Loading	xxxxx	
a. Organic		
b. Hydraulic		
c. Industrial		
d. Toxic		
e. Seasonal Variation		
f. Infiltration/Inflow		
g. Return Process Streams		

*A - Major effect on a long-term repetitive basis.
B - Minimum effect on a routine basis or major effect on a periodic basis.
C - Minor effect.
NR - No rating.

Checklist of Performance-Limiting Factors (continued)

Factor	Rating*	Comments
2. Unit Design Adequacy	xxxxx	
a. Preliminary		
b. Primary		
c. Secondary	xxxxx	
1) Process Flexibility		
2) Process Controllability		
3) "Aerator"		
4) Clarifier		
d. Advanced Waste Treatment	xxxxx	
1)		
2)		
3)		
e. Disinfection		
f. Sludge Wasting Capability		
g. Sludge Thickening		
h. Sludge Treatment		
i. Ultimate Sludge Disposal		

* A - Major effect on a long-term repetitive basis.
B - Minimum effect on a routine basis or major effect on a periodic basis.
C - Minor effect.
NR - No rating.

Checklist of Performance-Limiting Factors (continued)

Factor	Rating*	Comments
3. Miscellaneous	xxxxx	
a. Plant Location		
b. Unit Process Layout		
c. Lack of Unit Bypass		
d. Flow Proportioning to Units		
e. Alarm Systems		
f. Alternate Power Sources		
g. Process Automation		
h. Lack of Standy Units for Key Equipment		
i. Laboratory Space and Equipment		
j. Process Accessibility for Sampling		
k. Equipment Accessibility for Maintenance		
l. Plant Inoperability Due to Weather		
m. Equipment Malfunction		
D. Operation	xxxxxx	
1. Testing	xxxxxx	
a. Performance Monitoring		
b. Process Control Testing		

* A - Major effect on a long-term repetitive basis.
B - Minimum effect on a routine basis or major effect on a periodic basis.
C - Minor effect.
NR - No rating.

Checklist of Performance-Limiting Factors (continued)

Factor	Rating*	Comments
3. Process Control Adjustments	xxxxxx	
a. Wastewater Treatment Understanding		
b. Application of Concepts and Testing to Process Control		
c. Technical Guidance (Operations)		
d. Training		
e. Insufficient Time on Job		
4. O&M Manual/Procedures	xxxxxx	
a. Adequacy		
b. Use		
E. Miscellaneous	xxxxxx	
1.		
2.		
3.		
4.		
5.		
6.		
7.		
8.		
9.		
10.		
11.		
12.		
13.		

* A - Major effect on a long-term repetitive basis.
B - Minimum effect on a routine basis or major effect on a periodic basis.
C - Minor effect.
NR - No rating.

Definitions for Assessing Performance-Limiting Factors

Category	Explanation
A. Administration	
1. Plant Administrators	
a. Policies	Do staff members have authority to make required operation (e.g., adjust valve), maintenance (e.g., hire electrician), and/or administrative (e.g., purchase critical piece of equipment) decisions, or do policies require a strict adherence to a "chain of command" (which has caused critical decisions to be delayed and in turn has affected plant performance and reliability)? Does any established administrative policy limit plant performance (e.g., non-support of training; industrial contributions not being controlled; or plant funding too low because of campaign to avoid rate increases)?
b. Familiarity With Plant Needs	Do administrators have a first-hand knowledge of plant needs through plant visits or discussions with operators? If not, has this been a cause of poor plant performance and reliability through poor budget decisions, poor staff morale, poor operation and maintenance procedures, poor design decisions, etc.?
c. Supervision	Do the management styles, organizational capabilities, motivational skills, budgeting skills, or communication practices at any management level adversely impact the plant to the extent that performance is affected?
d. Planning	**Does lack of long range plans for facility replacement, emergency response, etc., adversely impact plant performance?**
2. Plant Staff	
a. Manpower	
1) Number	Does a limited number of people employed have a detrimental effect on plant operations or maintenance (e.g., not getting the necessary work done)?
2) Plant Coverage	Is plant coverage adequate such that necessary operational activities are accomplished? Can appropriate adjustments be made during the evenings, weekends or holidays?
3) Workload Distribution	Does the improper distribution of adequate manpower (i.e., a higher priority on maintenance tasks) prevent process adjustments from being made or cause them to be made at inappropriate times, resulting in poor plant performance?
4) Personnel Turnover	Does a high personnel turnover rate cause operation and/or maintenance problems that affect process performance or reliability?
b. Morale	
1) Motivation	Does the plant staff want to do a good job because they are motivated by self-satisfaction?
2) Pay	Does a low pay scale or benefits package discourage more highly qualified persons from applying for operator positions or cause operators to leave after they are trained?
3) Work Environment	Does a poor work environment create a condition for more "sloppy work habits" and lower operator morale?

c. Staff Qualifications	
1) Aptitude	Does the lack of capacity for learning or understanding new ideas by critical staff members cause improper O&M decisions leading to poor plant performance or reliability?
2) Level of Education	Does a low level of education result in poor O&M decisions? Does a high level of education cause needed training to be felt unnecessary?
3) Certification	Does the lack of adequately certified personnel result in poor O&M decisions?
d. Productivity	Does the plant staff conduct the daily operation and maintenance tasks in an efficient manner? Is time used efficiently?
3. Financial	
a. Funding	Does the lack of available funds (e.g., inadequate rate structure) cause poor salary schedules, insufficient spare parts that results in delays in equipment repair, insufficient money for capital outlays for improvements or replacement, etc.?
b. Expenditures	Does the manner in which available funds are used cause problems in obtaining needed equipment, staff, etc.? Are funds spent on lower priority items while needed, higher priority items are unfunded?
c. Bond Indebtedness	Does the annual bond debt payment limit the amount of funds available for other needed items such as equipment, staff, etc.?

B. Maintenance

1. Preventive	
a. Effective/Formal Program	Does the absence or lack of an effective scheduling and recording procedure cause unnecessary equipment failures or excessive downtime that results in plant performance or reliability problems?
b. Spare Parts Inventory	Does a critically low or nonexistent spare parts inventory cause unnecessary long delays in equipment repairs that result in degraded process performance?
2. Corrective	
a. Procedures	Are procedures available to initiate maintenance activities on observed equipment operating irregularities (e.g., work order system)? Does the lack of emergency response procedures result in activities that fail to protect process needs during breakdowns of critical equipment (e.g., maintaining oxygen supply to organisms during blower breakdowns)?
b. Critical Parts Procurement	Do delays in getting replacement parts caused by procurement procedures result in extended periods of equipment downtime?
c. Technical Guidance (Maintenance)	Is technical guidance for repairing or installing equipment necessary to decrease equipment downtime, is it available and retained?
3. General	
a. Housekeeping	Does a lack of good housekeeping procedures (e.g., grit channel cleaning; bar screen cleaning; unkempt, untidy, or cluttered working environment) cause an excessive equipment failure rate?
b. References Available	Does the absence or lack of good equipment reference sources result in unnecessary equipment failure and/or downtime for repairs (includes maintenance portion of O&M Manual, equipment catalogs, pump curves, etc.)?

c. Staff Expertise	Does the plant staff have the necessary expertise to keep the equipment operating and to make equipment repairs when necessary?
d. Technical Guidance (Maintenance)	Does inappropriate guidance for repairing, maintaining or installing equipment from a technical resource (e.g., equipment supplier or contract service) result in equipment downtime that adversely affects performance?
e. Equipment Age	Does the age or outdatedness of critical pieces of equipment cause excessive equipment downtime and/or inefficient process performance and reliability (due to unavailability of replacement parts)?

C. Design

1. Plant Loading	Does the presence of "shock" loading characteristics over and above what the plant was designed for, or over and above what is thought to be tolerable, cause degraded process performance by one or more of the loadings (a-e) listed below?
a. Organic	
b. Hydraulic	(e.g., high-volume on-off lift station pumps)
c. Industrial	
d. Toxic	
e. Seasonal Variation	(e.g., winter flows at ski resort)
f. Infiltration/Inflow	Does excessive infiltration or inflow cause degraded process performance because the plant cannot handle the extra flow?
g. Return Process Streams	Does excessive volume and/or a highly organic or toxic return process flow stream cause adverse effects on process performance, equipment problems, etc.?
2. Unit Design Adequacy	
a. Preliminary	Do the design features of any preliminary treatment unit cause problems in downstream equipment or processes that have led to degraded plant performance?
b. Primary	Does the performance of the primary treatment unit contribute to problems in downstream equipment or processes that have degraded plant performance? Do the units have any design problem areas that have caused less than required performance to meet overall treatment objectives?
c. Secondary	
1) Process Flexibility	Does the unavailability of adequate valves, piping, etc. limit plant performance and reliability when other modes of operation of the existing plant can be utilized to improve performance (e.g., operate activated sludge plant in plug, step, or contact stabilization mode; operate RBCs in step loading mode)?
2) Process Controllability	Do the existing process control features provide adequate adjustment and measurement over the appropriate flows (e.g., return sludge) in the range necessary to optimize process performance; or is the flow difficult to adjust, variable once adjusted, not measured and recorded, not easily measurable, etc.?

3) "Aerator"	Does the type, size, shape, or location of the "aerator" (aeration basin, trickling filter, RBC, etc.) hinder its ability to adequately treat the sewage and provide for stable operation? Is oxygen transfer capacity inadequate?
4) Clarifier	Does a deficient design cause poor sedimentation due to the size, type, or depth of the clarifier; placement or length of the weirs; or does inadequate scum removal adversely affect performance?
d. Advanced Waste Treatment	Advanced waste treatment is any process of wastewater treatment that upgrades water quality to meet specific effluent limits that cannot be met by conventional primary and secondary treatment processes (i.e., nitrification towers, chemical treatment, multimedia filters). (Space is available in the Checklist to accommodate advanced processes encountered during the CPE.)
e. Disinfection	Does the unit have any design limitations that contribute to its inability to accomplish disinfection (i.e., proper mixing, detention time, feed rates, feeding rates proportional to flow, etc.)?
f. Sludge Wasting Capability*	Does the inability to waste sludge adversely affect plant performance? Can desired volume of sludge be wasted? Can sludge wasting be adequately controlled? Can sludge wasted be sampled without extreme difficulty?
g. Sludge Thickening/Dewatering*	Does the type or size of the sludge thickening/dewatering process hinder sludge wasting capability or sludge treatment such that plant performance is adversely affected?
h. Sludge Treatment*	Does the type or size of the sludge treatment process hinder sludge stabilization (once sludge has been removed from the wastewater treatment system), thereby causing process operation problems (e.g., odors, limited sludge wasting, poor quality recycle streams, etc.)?
i. Ultimate Sludge Disposal*	Is the ultimate sludge disposal program, including facilities and disposal area, of sufficient size and type to adequately handle the sludge production from the plant? Are there any specific areas that limit ultimate sludge disposal such as seasonal weather variations or crop harvesting?

* For the purposes of this manual, these factors are assessed on their impact on a plant to achieve final effluent requirements and are not assessed relative to meeting sludge regulation criteria.

3. Miscellaneous	The design "miscellaneous" category covers areas of design inadequacy not specified in the previous design categories. (Space is available in the Checklist to accommodate additional items not listed.)
a. Plant Location	Does a poor plant location or poor roads leading into the plant cause it to be inaccessible during certain periods of the year (e.g., winter) for chemical or equipment delivery or for routine operation?
b. Unit Process Layout	Does the arrangement of the unit processes cause inefficient utilization of operator's time for checking various processes, collecting samples, making adjustments, etc.?
c. Lack of Unit Bypass	Does the lack of a unit bypass cause plant upset and long-term poor treatment when a short-term bypass could have minimized pollutional load to the receiving waters; cause necessary preventive or emergency maintenance items to be cancelled or delayed; or cause more than one unit to be out of service when maintaining only one unit?

d. Flow Proportioning Units	Does inadequate flow proportioning or flow splitting to duplicate units cause problems or partial unit overloads that degrade effluent quality or hinder achievement of optimum process performance?
e. Alarm Systems	Does the absence or inadequacy of an alarm system for critical pieces of equipment or processes cause degraded process performance?
f. Alternate Power Source	Does the absence of an alternate power source cause problems in reliability of plant operation leading to degraded plant performance?
g. Process Automation	Does the breakdown or improper workings of automatic process monitoring or control features cause degradation of process performance? Could the availability of automatic monitoring or control devices enhance process control and improve plant performance?
h. Lack of Standby Units for Key Equipment	Does the lack of standby units for key equipment cause degraded process performance during breakdown or during necessary preventive maintenance activities?
i. Laboratory Space and Equipment	Does the absence of an adequately equipped analytyical and/or process control laboratory limit plant performance?
j. Process Accessibility for Sampling	Does the inaccessibility of various process flow streams (e.g., recycle streams) for sampling prevent needed information from being obtained?
k. Equipment Accessibility for Maintenance	Does the inaccessibility of various pieces of equipment cause extensive downtime or difficulty in making needed repairs or adjustments?
l. Plant Inoperability Due to Weather	Are certain units in the plant extremely vulnerable to weather changes (e.g., cold temperatures) and, as such, do not operate at all or do not operate as efficiently as necessary to achieve required performance?
m. Equipment Malfunction	Does malfunctioning equipment (i.e., not functioning in accordance with design) cause deteriorated process performance?

D. Operation

1. *Testing*

a. Performance Monitoring	Are the monitoring tests truly representative of plant performance (e.g., does a sludge accountability analysis support plant performance records)?
b. Process Control Testing	Does the absence or wrong type of process control testing cause improper operational control decisions to be made?

2. *Process Control Adjustments*

a. Wastewater Treatment Understanding	Is the operator's lack of a basic understanding of wastewater treatment (e.g., limited exposure to terminology, lack of understanding of the function of unit processes, etc.) a factor in poor operational decisions and poor plant performance or reliability?
b. Application of Concepts and Testing to Process Control	Is the staff deficient in the application of their knowledge of wastewater treatment and interpretation of process control testing such that improper process control adjustments are made?
c. Technical Guidance (Operations)	Does inappropriate operational information received from a technical resource (e.g., design engineer, equipment representative, State trainer
d. Training	Does inattendance at available training programs result in poor process control decisions by the plant staff or administrators?

e. Plant Familiarity	Does the short time on the job and associated unfamiliarity with plant needs result in the absence of process control adjustments or in improper process control adjustments being made (e.g., opening or closing a wrong valve, turning on or off a wrong pump, etc.)?
4. O&M Manual/Procedures	
a. Adequacy	Does inappropriate guidance provided by the O&M Manual/Procedures result in poor or improper operational decisions?
b. Use	Does a good O&M Manual/Procedures, not used by the operator, cause poor process control and poor treatment that could have been avoided?

E. Miscellaneous

The "miscellaneous" category allows addition of factors not covered by the above definitions. Space is available in the Checklist to accommodate these additional items.

Appendix B

CPE Summary Sheet for Ranking Performance-Limiting Factors

CPE Summary Sheet for Ranking Performance-Limiting Factors

Plant Name/Location ______________________________

CPE Performed by ______________________________ Date ______________

Plant Type:	
Design Flow:	
Actual Flow:	
Plant Performance Summary:	

RANKING TABLE

Ranking	Rating	Performance-Limiting Factor
1	A	
2	A	
3	A	
4	A	
5	B	
6	B	
7		
8		
9		
10		
11		
12		
13		
14		
15		

CPE Summary Sheet Terms

PLANT TYPE	Brief but specific description of type of plant (e.g., two-stage trickling filter with anaerobic digester or activated sludge with aerobic sludge digestion and drying beds).
DESIGN FLOW	Daily average plant design flow rate as of most recent upgrade.
ACTUAL FLOW	Daily average wastewater flow rate for current operating condition (e.g., for past year).
PLANT PERFORMANCE SUMMARY	Brief description of plant performance as related to discharge permit requirements (e.g., for past year).
RANKING TABLE	A list of the major causes of decreased plant performance and reliability.
RANKING	Causes of decreased plant performance and reliability, with the most critical factors listed first. (Typically only "A" and "B" factors are listed.)
RATING PERFORMANCE-LIMITING FACTORS	Items identified from the Checklist (Appendix A).

Appendix C

Example CPE Report

Results of a CPE at the Springfield, Kansas POTW

Facility Background

The Springfield POTW is a rotating biological contactor (RBC) type of treatment plant designed for an average daily wastewater flow of 87.6 L/s (2.0 mgd). The plant was originally completed as a primary treatment plant in 1965 and upgraded for secondary treatment in 1980. The plant serves the City of Springfield with an estimated population of 9,000. A railcar washing operation is thought to be the source of the only significant industrial waste, but sampling has not confirmed this.

Plant records indicated that wastewater flows had been averaging close to design flow; however, flow calibration during the CPE indicated that flow was actually about 52.6 L/s (1.2 mgd), or only 60 percent of design flow. Current organic loading was estimated to also be about 60 percent of design.

The Springfield plant consists of the following unit processes:

- Vortex grit chamber
- Mechanical bar screen
- 23-cm (9-in) Parshall flume
- Lift station
- One 18-m (60-ft) diameter primary clarifier
- Four-stage RBCs (12 shafts)
- Two 6 m x 33 m (20 ft x 110 ft) secondary clarifiers
- Two-cell chlorine contact chamber
- Two 11-m (35-ft) diameter anaerobic digesters (Note: During the CPE, the second-stage digester was not in service.)
- 2,800 m^2 (30,000 sq ft) drying beds

The Springfield plant is required to meet standard secondary treatment effluent requirements with 20,000/40,000 fecal coliform limits. Monthly average NPDES monitoring data indicate performance of the plant has generally been within standards, but individual daily analyses indicated violation of effluent requirements. During the CPE, solids loss from both the primary and secondary clarifiers was observed.

Major Unit Process Evaluation

Major plant processes were evaluated for their capacity to adequately treat current loadings and the general applicability of a CCP to improve performance. Current hydraulic loadings were based on historical plant flow data records. During the CPE, the totalizer and flow recording devices were evaluated by comparing depth measurements taken in the Parshall flume to the instrument recordings. Measured flows were within 8 percent of indicated flows. Organic loading on the RBC as measured by soluble BOD$_5$ was estimated using 30 percent total BOD removal in the primary clarifier and 50 percent of the primary effluent total BOD as soluble BOD.

A sludge accountability analysis indicated that reported effluent quality was probably representative of actual effluent quality.

The ability to handle current loads was assessed using a numerical point system, which resulted in the plant being categorized Type 1, 2, or 3 as described below:

- Type 1. Facilities are adequate. Performance problems could be alleviated with training and/or minor facility modifications.
- Type 2. Facilities are marginal. Improved performance from existing facilities may be possible by addressing performance-limiting factors.
- Type 3. Facilities are inadequate. To consistently meet effluent requirements, major facility modifications are necessary.

The results of the major unit process evaluation are shown in Table C-1.

Table C-1. Springfield, Kansas POTW Major Unit Process Evaluation.

	Assessed Type
Aerator	1
Secondary Clarifier	1
Sludge Handling Capability	2
Total of Major Processes	1
Plant Type	2

As shown in Table C-1, the aerator, secondary clarifier, and the total of major processes all received sufficient points to receive a Type 1 classification. Sludge handling capability received a Type 2 classification. The major limitation regarding sludge handling was ultimate sludge disposal capability in winter.

The evaluation of major unit processes indicates that sludge handling will likely require supplemental capacity, but the other major processes have adequate capacity. In general, the CCP approach appears applicable if the ultimate sludge disposal capacity can be addressed.

The potential capacity of major unit processes in the Springfield plant is illustrated in Table C-2. The horizontal bar graph associated with each major process depicts the potential capacity of that process.

Primary clarifiers, secondary clarifiers, and anaerobic digesters were all projected to have capacities slightly greater than design. The chlorine contact basin was rated at design capacity. The RBCs were not projected to have enough capacity to adequately treat design loadings; however, the units were rated to have adequate capacity to treat current flows.

The ultimate sludge disposal capability as represented by the sludge drying beds was assessed to be inadequate at current and design flows. The limitation in ultimate sludge disposal is during the winter when the drying beds freeze and do not dry.

Performance-Limiting Factors

During the CPE, the plant's performance-limiting factors in the areas of design, administration, operation, and maintenance were identified. These factors are listed below and the most significant ones briefly discussed.

1. Sewage Treatment Understanding (Operation). A lack of understanding of biological treatment process fundamentals and operational requirements and goals significantly limit plant performance. This limitation could be addressed with onsite training over a period of months or by periodic attendance at seminars, schools, etc., over a period of many years.
2. Ultimate Sludge Disposal (Design). Existing drying beds are inadequate for needed year-round sludge disposal. Additional beds may be a long-term solution. Liquid sludge haul to farmland may be a workable interim solution. Documentation for the need and administrative training are necessary.
3. Process Control Testing (Operation). An almost complete lack of process control testing existed prior to the CPE. Base-level testing was initiated during the CPE. Onsite training is required to optimize process control testing and to teach the operational staff to properly apply the test results to process controls.
4. Return Process Streams (Design). Secondary sludge being returned to the primary clarifier was causing primary clarifier "bulking." Anaerobic digester supernatant return was also adversely impacting plant performance. The capability to minimize the adverse impact of return process streams can be acquired through long-term, onsite traning.
5. Administrative Familiarity With Plant Needs (Administration). Through past poor communication and improper operation, the plant administrators have been misled regarding plant needs. Increased familiarity in the areas of treatment fundamentals, operation and maintenance requirements, funding needs, and safety concerns is needed.
6. Process Controllability (Design). Existing flow-splitting capability to the RBCs is inadequate. Correction of this deficiency will likely require minor design modifications.

Other factors that contributed to limited performance, but in a less significant way, include: an inadequate spare parts inventory, limited staff expertise in handling emergency maintenance, a lack of an alternate power source, and a lack of needed sample taps.

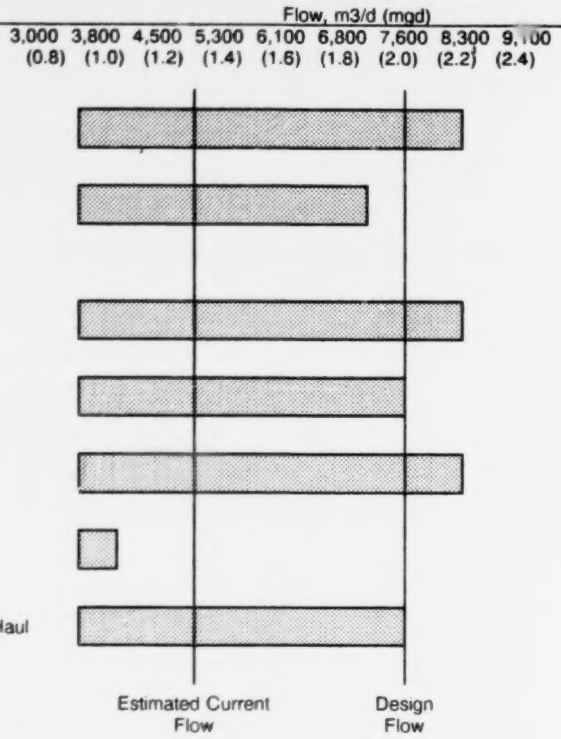
Performance Improvement Activities

Improved effluent quality, to consistently meet NPDES permit limits, is expected if a CCP is implemented.

Costs

Costs associated with a 12-month CCP at Springfield would be for the CCP facilitator and for laboratory equipment to allow process control testing, minor modifications (i.e., sample taps and flow splitting), and supplemental winter sludge disposal (Table C-3). Estimated costs for conducting a CCP at Springfield are listed in Table C-3:

Table C-2. Springfield, Kansas POTW Capacity Potential.



Major Unit Process	Comments
Primary Clarifier	Rated at 33 $m^3/m^2/d$ (800 gpd/sq ft). Estimated 30% BOD_5 removed.
RBCs	Rated at 3.9 kg $SBOD/m^2/d$ (0.8 lb/d/1,000 sq ft) lower than 4.9 kg $SBOD/m^2/d$ (1.0 lb/d/1,000 sq ft) because of sidestream return.
Secondary Clarifier	Rated at 20 $m^3/m^2/d$ (500 gpd/sq ft because of configuration.
Chlorine Contact	30 minute average hydraulic detention time.
Digesters	Rated at 30 days detention time. Assume 4.5% combined sludge wasted to digester.
Ultimate Disposal	42 days turnover time at current flow; inadequate in winter.
Ultimate Disposal Liquid Haul to Land	Farm land is available. Will require truck or contract haul.

Table C-3. Springfield, Kansas Estimated CCP Costs

Item	Cost ($)
CCP Facilitator	9,500 (one-time)
City Costs	
Minor Modifications	7,000 (one-time)
Lab Equipment	400 (one-time)
Supplementary Sludge Disposal	18,000 (annual)
	25,400
Total CCP Costs	34,900

Appendix D

Data Collection Forms Used In Conducting CPEs

Form	Title
D-1	Preliminary Plant Information
D-2	Administration Data
D-3	Design Data
D-4	Operations Data
D-5	Maintenance Data
D-6	Performance Data
D-7	Interview Data

Form D-1
Preliminary Plant Information to Collect by Telephone

Plant Name ______________________________

Phone Contact ______________________________

Position ______________________________

Phone. No. ______________ Date ______________

Design Flow ______________ Current Flow ______________

Service Population ______________________________

Year Plant Built ______________ Most Recent Upgrade ______________

Directions to Plant ______________________________

____

____

____

____

Major Processes (type and size):

Preliminary Treatment ______________________________

Primary Treatment ______________________________

Secondary Treatment

Aeration Basin ______________________________

Trickling Filter ______________________________

Clarifier ______________________________

Disinfection ______________________________

Unusual Processes or Equipment ______________________________

____

____

____

Any processes or equipment currently not operational ______________________________

____

____

____

Who does performance monitoring tests? ______________________________

Who does process control test? ______________________________

What process control and laboratory test equipment is available? ______________________________

Plant coverage (8 am - 5 pm, 24 hr, etc.) ______________________________

Work hours of key individuals ______________________________

Known conflicts with scheduling fieldwork ______________________________

Contact for scheduling fieldwork ______________________________

Administrator or owner (responsible official) ______________________________

Who has records on the budget? ______________________________

Who is consultant? ______________________________

Information resources (availability):

As-built construction plans ______________________________

O&M Manual ______________________________

Monitoring records ______________________________

Equipment literature ______________________________

Process control records ______________________________

Form D-2
Administration Data

A. Name and Location

Name of Facility

Type of Facility

Owner

Administrative Office:

Mailing Address

Primary Contact

Title

Telephone No.

Treatment Plant:

Mailing Address

Primary Contact

Title

Telephone No.

B. Kickoff Meeting

Purpose of CPE
- Background
- Assess plant potential for achieving compliance
- Identify current factors limiting performance
- Outline follow-up activities

Schedule of Events	Day	Time
a. Kickoff Meeting		
b. Plant Tour		
c. Review Budget/User Charge Ordinance/Revenues		
d. On-site Data Collection/Review O&M Manual/ NPDES Permit/Design Data/Operating Records		
e. Conduct Personnel Interviews		
f. Exit Meeting		

B. Kickoff Meeting (continued)

Personnel Interviews Scheduling Sheets (includes off-site administrators/owners, budgeting personnel, laboratory, maintenance personnel, plant administrators, shift personnel, operators, etc.)

Person	Title	Day	Time

B. Kickoff Meeting (continued)

Attendance List

Municipality ______________________________ Date ____________________

Name	Title/Dept.	Telephone No.

C. Permit Information (attach copies of pertinent pages from actual permit if available)

Permit Number ______________________________

Date Permit Issued ______________________________

Date Permit Expires ______________________________

Receiving Stream ______________________________

Effluent Limits and Monitoring Requirements:

Parameter*	Maximum Monthly Average	Maximum Weekly Average	Monitoring Frequency Required	Sample Type Required
Flow, mgd	______	______	______	______
BOD_5, mg/L	______	______	______	______
BOD_5, lb/d	______	______	______	______
TSS, mg/L	______	______	______	______
TSS, lb/d	______	______	______	______
Fecal Coliform, No./100 ml	______	______	______	______
Chlorine Residual, mg/L	______	______	______	______
pH, units	______	______	______	______
Phosphorus, mg/L	______	______	______	______
Phosphorus, lb/d	______	______	______	______
Ammonia, mg/L	______	______	______	______
Ammonia, lb/d	______	______	______	______
Oil & Grease, mg/L	______	______	______	______
Others	______	______	______	______
	______	______	______	______
	______	______	______	______

* Note if seasonal limit.

D. Organization

Governing Body (name and scheduled meetings)

Structure

From Governing Body to POTW

POTW Staff

Staff Meetings (formal/informal)

D. Organization (continued)

Reporting Requirements (formal/informal)

Service Area (general description - residential, industrial, seasonal influences, etc.)

Compliance Schedule

Observations (openess, awareness of plant needs, management style, etc.)

E. Personnel

Plant

No.	Title/Name	Certification	Pay Scale	% of Time at POTW

Off-Site

No.	Title/Name	Pay Scale	% of Time Allocated to POTW

F. Training

Operator Training Budget ______________________________

____

____

Training Incentives ______________________________

____

____

Training Over Last Year ______________________________

____

____

G. Plant Coverage

Weekdays

Shifts (times/overlap?/number per shift)

Weekends & Holidays

Alarms (on what processes? dialer?)

H. Plant Budget/Expenditures (attach copy of actual budget and/or expenditures if available)

Budget Year: ________________ to ____________ _____

Expenditure Period: ________________ to ________________

Category	Budget Amount	Expenditure Amount
Administrative Salaries (including fringes)		
Plant Staff Salaries (including fringes)		
Utilities		
Electric (see Part I)		
Gas (see Part I)		
Chemicals		
Vehicles		
Training		
Operations Subtotal		
Capital Outlay (see Part J)		
Bond Debt Retirement		
Reserve		
Capital Improvement Subtotal		
Plant Total		

Observations

____

____

____

Budget Prepared By: ____

I. Energy Consumption

Electricity

Source of Information ______________________________

Base Cost __________ ¢/kWh (attach rate schedule if available).

Demand Cost __________

Month/Year	Days in Billing Period	Energy Usage (kWh)	Energy Demand Cost	ECA Cost*	Base Cost	Total Cost
Total						

---

*ECA = Energy Cost Adjustment, which is the pass-through cost allowed to public service companies for increased fuel cost to generate electricity.

I. Energy Consumption (continued)

Natural Gas/Fuel Oil/LPG

Source of Information ______________________________

Unit Cost __________ (attach rate schedule if available)

Month/Year	Days in Billing Period	Usage	Cost
Total			
Average			

Miscellaneous (Fuel Oil, Digester Gas, etc.):

J. Capital Outlays

Bond Retirement

Bond Type	Year Issued	Duration	Interest Rate	Annual Payment	Description of Project Financed

Capital Improvement Reserve (Self sustaining utility? Exceed bond requirements? Replacement philosophy?)

Capital Replacement Plan (Available? Items scheduled for replacement? Attach if available.)

Observations

K. Revenue

User Charges

Type of Connection	Fee	User Fee Revenue
Residential		
Non-Residential (Industry, Commercial, Government Institutions)		
Other		

Connection Fee

Type of Connection	Fee	Connection Fee Revenue
Residential		
Non-Residential		

Other Sources of Revenue

Total Revenue for Evaluation Period (see Part H)

Miscellaneous

Are rates and budgets reviewed annually?

When was last rate increase? (How much?)

Proposed increases?

L. Exit Meeting

Attendance List

Municipality ______________________ Date ____________

Name	Title/Dept.	Telephone No.

Attach Copy of Exit Meeting Handouts

Form D-3
Design Data

A. Plant Flow Diagram (attach if available)

B. Plant Solids Handling Diagram (attach if available)

C. Upgrading and/or Expansion History (historical studies, current evaluations, proposed modifications, etc.)

D. Influent Characteristics

Average Daily Flow:	Design	______	mgd x 3,785 =	______	m3/d
	Current	______	mgd x 3,785 =	______	m3/d
Maximum Daily Fow:	Design	______	mgd x 3,785 =	______	m3/d
	Current	______	mgd x 3,785 =	______	m3/d
Maximum Hourly Flow:	Design	______	mgd x 3,785 =	______	m3/d
	Current	______	mgd x 3,785 =	______	m3/d
Average Daily BOD$_5$:	Design	______	lb x 0.454 =	______	kg
	Current	______	lb x 0.454 =	______	kg
Average Daily TSS:	Design	______	lb x 0.454 =	______	kg
	Current	______	lb x 0.454 =	______	kg

Infiltration Inflow

Seasonal Variations

Major Industrial Vastes

Name	Flow	BOD$_5$ Load	TSS Load	Other
______	______	______	______	______
______	______	______	______	______
______	______	______	______	______
______	______	______	______	______

Collection System

Lift Stations

Number of Resiential Taps Served

Population Servd

E. Unit Processes

Flow Measurement

(Form for each flow measuring device)

Flow Stream Measured ______________________________

Control Section:

Type and Size ______________________________

Location ______________________________

Comments (operational problems, maintenance problems, unique features, preventive maintenance procedures, etc.):

Recorder

Name ____________________ Model ____________________

Flow Range ______________________________

Calibration Frequency ______________________________

Date of Last Calibration ______________________________

Totalizer ______________________________

Comments (operation and design problems, unique features, etc.):

Accuracy Check During CPE

Method of Check:

Results:

E. Unit Processes (continued)

Pumping

(Complete as many forms as necessary)

Flow Stream Pumped	Type	No. of Pumps	Name	Model	hp	Capacity	Head

Comments: (flow control, suitability of installed equipment, results of capacity check, etc.)

Comments:

Comments:

Preliminary Treatment

Mechanical Bar Screen

Name ______________________________

Model ______________ Horsepower ______________

Bar Screen Width __________ inch x 2.54 = __________ cm

Bar Spacing __________ inch, O.C. x 2.54 = __________ cm

Within Building? __________ Heated? __________

Description of Operation:

Hand-Cleaned Bar Screen

Bar Screen Width __________ inch x 2.54 = __________ cm

Bar Spacing __________ inch, O.C. x 2.54 = __________ cm

Cleaning Frequency ______________________________

Within Building? __________ Heated __________

Description of Operation:

Screenings Volume:

Normal __________ cu yd x 0.75 = __________ m^3/d

Peak __________ cu yd x 0.75 = __________ m^3/d

Screenings Disposal

Comments

E. Unit Processes (continued)

Preliminary Treatment

Comminutor

Name ____

Model ____________________ **Horsepower** ____________________

Within Building? __________ **Heated?** __________

Maintenance:

Comments:

Grit Removal

Description of Unit:

Grit Volume:

Normal ____________ cu yd x 0.75 = ____________ m3/d

Peak ____________ cu yd x 0.75 = ____________ m3/d

Disposal of Grit:

Comments:

E. Unit Processes (continued)

Primary Treatment

Primary Clarifier(s)

Number ____________ Surface Dimensions ____________
____

Water Depth (Shallowest) ____________ ft x 0.3 = ____________ m

Water Depth (Deepest) ____________ ft x 0.3 = ____________ m

Weir Location ____________

Weir Length ____________ ft x 0.3 = ____________ m

Total Surface Area ____________ sq ft x 0.093 = ____________ m²

Total Volume ____________ cu ft x 0.028 = ____________ m³

Flow (Design) ____________ mgd x 3,785 = ____________ m³/d

(Operating) ____________ mgd x 3,785 = ____________ m³/d

Weir Overflow Rate
(Design) ____________ gpd/ft x 0.012 = ____________ m³/m/d

(Operating) ____________ gpd/ft x 0.012 = ____________ m³/m/d

Surface Settling Rate
(Design) ____________ gpd/sq ft x 0.04 = ____________ m³/m²/d

(Operating) ____________ gpd/sq ft x 0.04 = ____________ m³/m²/d

Collector Mechanism Name ____________

Model ____________ Horsepower ____________

Scum Collection and Treatment:

Scum Volume:

Scum Treatment/Disposal:

E. Unit Processes (continued)

Secondary Treatment (Activated Sludge)

Aeration Basin(s)

Number ____________ **Surface Dimensions** ____________

____

Water Depth ____________ **ft x 0.3 =** ____________ **m**

Total Volume ____________ **cu ft x 7.48 =** ____________**gal**

Flow (Design) ____________ **mgd x 3,785 =** ____________ **m^3/d**

(Operating) ____________ **mgd x 3,785 =** ____________ **m^3/d**

Wastewater Detention Time (Design) ____________ **hr**

(Operating) ____________ **hr**

BOD_5 Loading

(Design) ____________ **lb/d/1,000 cu ft x 0.16 =** ____________ **$kg/m^3//d$**

(Operating) ____________ **lb/d/1,000 cu ft x 0.16 =** ____________ **$kg/m^3/d$**

Covered? ____________

Comments:

Modes of Operation (current and other options; i.e., complete mix, plug flow, step loading, tapered aeration - sketch options):

E. Unit Processes (continued)

SecondaryTreatment (Contact Stabilization)

Contact Basin

Surface Dimensions (ea unit)________________ No. of Units________________

Water Depth ________________ ft x 0.3 = ____________ m

Volume (ea)________________ cu ft x 7.48 = ____________gal

Flow (Design) ________________ mgd x 3,785 = ____________ m^3/d

(Operating) ________________ mgd x 3,785 = ____________ m^3/d

Sewage Detention Time (Design) ________________ min

(Operating) ________________ min

Covered?

Comments:

Reaeration Basin

Surface Dimensions (ea unit)________________ No. of Units________________

Water Depth ________________ ft x 0.3 = ____________ m

Volume (ea)________________ cu ft x 7.48 = ____________gal

Hydraulic Detention Time at 100 Percent Return

(Design) ________________ hr

(Operating) ________________ hr

Flexibility to Operate as Conventional or Step Feed:

Covered?

Comments:

E. Unit Processes (continued)

Secondary Treatment (Oxygen Supply)

Surface Mechanical Aeration

No. of Aerators ____________ Name ____________

Model ____________ Horsepower ____________

Rated Capacity ____________ lb/hr x 0.454 = ____________ kg/hr

Speed Control:

Submergence Control:

Diffused Aeration

Blowers

No. of Blowers ____________ Name ____________

Model ____________ Horsepower ____________

Capacity ____________ cfm x 0.028 = ____________ m^3/min

Minimum Inlet Air Temperature ____________

Diffusers

Types of Diffusers (coarse, fine, ceramic, stainless steel, etc.):

Manufacturer ____________ Model ____________

Water Depth ____________

Rated Standard Transfer Efficiency ____________

Water Temperature (maximum) ____________

Plant Elevation ____________

Jet Aeration

No. of Aerators ____________ Name ____________

Model ____________ Horsepower ____________

Rated Capacity ____________ lb/hr x 0.454 = ____________ kg/hr

Controls:

Comments

NOTE: See Appendix F for procedure for converting standard oxygenation rates to actual oxygenation rates.

E. Unit Processes (continued)

Secondary Treatment (Trickling Filter)

Filter(s)

Number ________ Covered? ________

Surface Dimensions ________

Media Type ________

Specific Surface Area ________ sq ft/cu ft x 32.8 = ________ m2/m3

Media Depth ________ ft x 0.3 = ________ m

Surface Area ________ sq ft x 0.093 = ________ m2

Media Volume ________ cu ft x 0.028 = ________ m3

Flow

(Design) ________ mgd x 3,785 = ________ m3/d

(Operating) ________ mgd x 3,785 = ________ m3/d

Organic Loading

(Design) ________ lb/d/1,000 cu ft x 0.016 = ________ kg/m3/d

(Operating) ________ lb/d/1,000 cu ft x 0.016 = ________ kg/m3/d

Hydraulic Loading

(Design) ________ gpd/sq ft x 0.04 = ________ m3/m2/d

(Operating) ________ gpd/sq ft x 0.04 = ________ m3/m2/d

Recirculation (description, ranges, current operation, sketch relative to clarifiers)

Mode of Operation

Climate (freezing in winter?)

Comments

E. Unit Processes (continued)

SecondaryTreatment (Rotating Biological Contactor - RBC)

RBC

Manufacturer ____________________

No. of Shafts ____________ No. of Stages ____________

Length of Shafts ________ ft x 0.3 = ________ m

Disk Diameter ________ ft x 0.3 = ________ m

Total Media Surface Area ________ sq ft x 0.093 = ________ m^2

Type of Drive (air, mechanical): ____________________

Covered? ____________ Heated? ____________

Flow

(Design) ________ mgd x 3,785 = ________ m^3/d

(Operating) ________ mgd x 3,785 = ________ m^3/d

Hydraulic Loading

(Design) ________ gpd/sq ft x 0.04 = ________ $m^3/m^2/d$

(Operating) ________ gpd/sq ft x 0.04 = ________ $m^3/m^2/d$

Temperature (Design) ________ °C (Operating) ________ °C

First Stage Organic Loading

(Design) ________ lb SBOD/d/1,000 sq ft x 4.88 = ________ g $SBOD/m^2/d$

(Operating) ________ lb SBOD/d/1,000 sq ft x 4.88 = ________ g $SBOD/m^2/d$

Total System Organic Loading

(Design) ________ lb SBOD/d/1,000 sq ft x 4.88 = ________ g $SBOD/m^2/d$

(Operating) ________ lb SBOD/d/1,000 sq ft x 4.88 = ________ g $SBOD/m^2/d$

Flexibility to Distribute Load to Stages (sketch)

Load Cells Available?

Comments

E. Unit Processes (continued)

SecondaryTreatment (Activated Biofilter - ABF)

Biocell

Manufacturer ____________________ No. of Cells ____________________

Surface Dimensions ____

Total Surface Area ____________ sq ft x 0.093 = ____________ m^2

Media Depth ____________ ft x 0.3 = ____________ m

Total Media Volume ____________ cu ft x 0.028 = ____________ m^3

Media Type ____

Specific Surface Area ____________ sq ft/cu ft x 32.8 = ____________ m^2/m^3

BOD_5 Loading

(Design) ____________ lb/d/1,000 cu ft x 0.016 = ____________ $kg/m^3/d$

(Operating) ____________ lb/d/1,000 cu ft x 0.016 = ____________ $kg/m^3/d$

Recirculation Tank

Dimensions (LxWxD) ____________ ft x 0.3 = ____________ m

Volume ____________ cu ft x 7.48 = ____________gal

Aeration Basin

Surface Dimensions ____

Depth ____________ ft x 0.3 = ____________ m

Volume ____________ cu ft x 7.48 = ____________ gal

Hydraulic Detention Time (Design) ____________ min (Operating) ____________ min

Comments

E. Unit Processes (continued)

SecondaryTreatment (Secondary Clarifiers)

Number ______________ Surface Dimensions ______________________

____

____

Water Depth (Shallowest) ________ ft x 0.3 = ________ m

Water Depth (Deepest) ________ ft x 0.3 = ________ m

Weir/Launder Location(s) ______________________

Percent of Clarification Developed by Launders ______________

Weir Length ____________ ft x 0.3 = ________ m

Weir Overflow Rate

(Design) ____________ gpd/ft x 0.012 = ________ m3/m/d

(Operating) ____________ gpd/ft x 0.012 = ________ m3/m/d

Total Surface Area ____________ sq ft x 0.093 = ________ m2

Total Volume ____________ cu ft x 0.028 = ________ m3

Flow (Design) ____________ mgd x 3,785 = ________ m3/d

(Operating) ____________ mgd x 3,785 = ________ m3/d

Surface Settling Rate

(Design) ____________ gpd/sq ft x 0.04 = ________ m3/m2/d

(Operating) ____________ gpd/sq ft x 0.04 = ________ m3/m2/d

Hydraulic Detention Time (Design) ________ hr (Operating) ________ hr

(Actual From Dye Test) ________ hr

Collector Mechanism Name ______________________

Model ______________ Horsepower ______________

Return Sludge Collector Mechanism Type ______________________

Mechanical Seal Location (center well?/collector arm?):

Scum Collection and Removal:

Scum Volume:

Normal ____________ cu yd x 0.75 = ____________ m3/d

Peak ____________ cu yd x 0.75 = ____________ m3/d

Scum Treatment/Disposal:

E. Unit Processes (continued)

Secondary Treatment (Stabilization Ponds)

Number ______________ Surface Dimensions ______________________
____
____

Water Depth #1 ________ ft x 0.3 = ________ m Length:Width Ratio ____________
Water Depth #2 ________ ft x 0.3 = ________ m Length:Width Ratio ____________
Water Depth #3 ________ ft x 0.3 = ________ m Length:Width Ratio ____________

Flow (Design) ______________ mgd x 3,785 = ________ m^3/d
(Operating) ______________ mgd x 3,785 = ________ m^3/d

Hydraulic Detention Time (Design) ________ days (Operating) ________ days

BOD_5 Loading
(Design) ______________ lb/ac/d x 1.12 = ________ kg/ha/d
(Operating) ______________ lb/ac/d x 1.12 = ________ kg/ha/d

Type of Aeration ____________________ No. of Aerators/Pond #1 ____________
Type of Aeration ____________________ No. of Aerators/Pond #2 ____________
Type of Aeration ____________________ No. of Aerators/Pond #3 ____________

Name ____________ Model ______________ Horsepower ____________

No. of Blowers ________ Name ____________ Model ______________

Horsepower ____________ Air Capacity ______________________

Mixing Pond #1 ________ $hp/10^6$ gal x 0.0002 = ________ kW/m^3
Mixing Pond #2 ________ $hp/10^6$ gal x 0.0002 = ________ kW/m^3
Mixing Pond #3 ________ $hp/10^6$ gal x 0.0002 = ________ kW/m^3

Recirculation Description ____
____
____

Ratio of Recirculation to Flow: (Design) ____________ (Operating) ____________

Flexibility (series/parallel operation; discharge structure) ____________________
____
____

Comments (short-circuiting?, etc.)

E. Unit Processes (continued)

Chlorine Disinfection

Contact Basin(s)

Number ______

Surface Dimensions ______

Channel Length-to-Width Ratio ______ No. of Bends ______

Water Depth ______ ft x 0.3 = ______ m

Total Volume ______ cu ft x 7.48 = ______ gal

Detention Time: (Design) ______ min (Operating) ______ min

Drain Capability:

Scum Removal Capability:

Comments:

Chlorinator(s)

Name ______ Number ______

Capacity ______ lb/d x 0.454 = ______ kg/d

Type of Injection:

Flow Proportioned?

Feed Rate (Operating) ______ lb/d x 0.454 = ______ kg/d

Dosage (Operating) ______ mg/l

Comments:

E. Unit Processes (continued)

Ultra-Violet Disinfection

Number ______________________________

Length of Flow Path ____________ ft x 0.3 = ____________ m

Lamp Type ______________________________

Number of Lamps per Unit ______________________________

Lamp Length ____________ ft x 0.3 = ____________ m

Effective Arc Length ____________ ft x 0.3 = ____________ m

Nominal UV Output ____________ (W/ft arc) x 3.281 = ____________ W/m arc

Lamp Horizontal Spacing (center-to-center) ____________ in x 2.54 = ____________ cm

Lamp Vertical Spacing (center-to-center) ____________ in x 2.54 = ____________ cm

Flow (Design) ____________________ mgd x 3,785 = ____________ m^3/d

(Operating) ________________ mgd x 3,785 = ____________ m^3/d

Maximum Influent Bacterial Density ________________ No./100 mL

Average Influent TSS ____________ mg/l

Comments:

Sludge Handling Facilities

Primary Sludge

Description of Pumping Procedure (time clocks; variable speed pumps; etc.)

Method of Sludge Volume Measurement

Sampling Location

Sampling Procedure

Comments

Return Sludge

Description of Sludge Movement (scrape to clarifier hopper; pump to aeration basin inlet channels; etc.)

Controllable Capacity Ranges

(Low) ____________________ mgd x 3,785 = _____________ m^3/d

(High) ____________________ mgd x 3,785 = _____________ m^3/d

Method of Control

Method of RAS Volume Measurement

Sampling Location

Sampling Procedure

Comments

Waste Sludge

Description of Waste Procedure (variable-speed pump wastes from separate clarifier hopper; continuous or by time clock; etc.)

Method of Waste Volume Measurement

Sampling Location

Sampling Procedure

Comments

E. Unit Processes (continued)

Treatment (Aerobic Digestion)

Digesters

Number of Basins ____________ Surface Dimensions ________________________________

Water Depth ____________ ft x 0.3 = ____________ m

Total Volume ____________ cu ft x 7.48 = ____________ gal

Covered? ____________________ Heated? ____________________

Mode of Operation

Oxygen Supply [Complete Form "Secondary Treatment (Oxygen Supply)"*]*

Decanting Procedure

Scum Removal

Comments

E. Unit Processes (continued)

Treatment (Anaerobic Digestion)

Primary Digesters

Number of Digesters ____________ Diameter ____________ ft x 0.3 = ____________ m

Sidewall Depth ____________ ft x 0.3 = ____________ m

Center Depth ____________ ft x 0.3 = ____________ m

Total Volume ____________ cu ft x 0.028 = ____________ m^3

Floating Cover? ______________________________

Flow (Design) ____________________ mgd x 3,785 = ____________ m^3/d

(Operating) ____________________ mgd x 3,785 = ____________ m^3/d

Detention Time (Design) ________________ days (Operating) ________________ days

Volatile Solids Loading (Design) ____________ lb/cu ft x 16 = ____________ kg/m^3

(Operating) ____________ lb/cu ft x 16 = ____________ kg/m^3

Heating

Manufacturer ______________________________ Model Number ________________________

Capacity ______________________ 10^6 Btu/hr x 0.29 = ________________ 10^6 W

Mixing

Manufacturer ______________________________ Type ______________________________

Number of Units ____________________

Sampling Ports

Mode of Operation

Gas System

Comments

E. Unit Processes (continued)

Treatment (Anaerobic Digestion)

Secondary Digesters

Number of Digesters ____________ Diameter ____________ ft x 0.3 = ____________ m

Sidewall Depth ____________ ft x 0.3 = ____________ m

Center Depth ____________ ft x 0.3 = ____________ m

Total Volume ____________ cu ft x 0.028 = ____________ m^3

Floating Cover? ________________________________

Flow (Design) ____________________ mgd x 3,785 = ____________ m^3/d

(Operating) ____________________ mgd x 3,785 = ____________ m^3/d

Detention Time (Design) ________________ days (Operating) ________________ days

Volatile Solids Loading (Design) ____________ lb/cu ft x 16 = ____________ kg/m^3

(Operating) ____________ lb/cu ft x 16 = ____________ kg/m^3

Heating

Manufacturer ________________________________ Model Number ________________________

Capacity ____________________ 10^6 Btu/hr x 0.29 = ________________ 10^6 W

Mixing

Manufacturer ________________________________ Type ________________________________

Number of Units ____________________

Sampling Ports

Mode of Operation

Gas System

Comments

E. Unit Processes (continued)

Dewatering

Sludge Drying Beds

Number of Beds **Dimensions (ea)** ____________ **Surface Area (Total)** ________________________

Covered? (Glass?) (Plastic?) ______________________ **Subnatant Drain To** ____________________

Dewatered Sludge Removal:

Mode of Operation (depth of sludge draw; seasonal operation; etc.):

Comments:

Other Dewatering Unit(s)

Type(s) of Unit(s) ____

Number of Units ________________ **Manufacturer** ______________________________________

Model __________________________________ **Horsepower** ____________________________

Loading Rate (Design) ____________________ **lb/hr x 0.454 =** ____________ **kg/hr**

(Operating) __________________ **lb/hr x 0.454 =** ____________ **kg/hr**

Polymer Used ____

lb/dry ton ____________ **x 0.5 =** ____________ **g/kg**

Cake Solids **(Design)** ____________ **percent solids**

(Operating) ____________ **percent solids**

Hours of Operation **(Design)** ____________ **hr/wk**

(Operating) ____________ **hr/wk**

Comments:

E. Unit Processes (continued)

Ultimate Disposal

Describe Procedure

Options

Seasonal Operation

Comments

E. Unit Processes (continued)

Summary of Plant Horsepower

Item	HP	Usage, %	Weighted HP
TOTAL			

F. Other Design Information

Standby Power (description of unit; automatic activation? capacity for which processes? frequency of use; etc.)

Alarm Systems (description of system; units covered; etc.)

Plant Automation (description of any plant automation not covered under more specific topics)

Miscellaneous (see miscellaneous disgn factors list in Appendix A)

Form D-4
Operations Data

A. Process Control Strategy and Direction

Who Sets Major Process Control Strategies?

Who Sets Daily Adjustments?

Where Is Help Sought When Desired Performance Is Not Achieved?

How Is Staff Input Utilized (Opinions, etc.)?

B. Specific Process Control Procedures

Sampling and Testing

Automatic Sampling

Sampling Locations

Composites (flow porportioned?)

Flow Measurement and Recording

	Influent	Prim. Sludge	RAS	WAS	To Digesters
Meter Calibration					
Readings Taken					

Onsite Accuracy Check (describe)

B. Specific Process Control Procedures (continued)

Primary Clarification
Sludge Removal (method of control/adjustment?)

Performance Monitoring (tests used? solids balance?)

Other

A. S. Secondary Systems
Sludge Mass Control (tests used? method of control/adjustment?)

Return Sludge Control (tests used? method of settling rates?)

Microscopy Used?

Filament Identification Capability?

DO Control (monitoring locations; frequency; control/adjustment?)

Mode Changes (capability; changed?)

Other

Fixed Film Secondary Systems
Secondary Clarifier Sludge Removal (adjustments?)

Soluble BOD Removal (monitored? recycle adjustments?)

Sidestream Returns (monitored? options?)

Other

B. Specific Process Control Procedures (continued)

Sludge Handling and Disposal
Purpose Relative to Other Processes

Sludge Thickening (monitored? process control/optimization?)

Sludge Stabilization (monitored? process control/optimization?)

Sludge Dewatering (monitored? process control/optimization?)

Sludge Disposal (meet requirements? monitoring? options?)

Miscellaneous
Unit Process Monitoring

Data Development/Interpretation

Trend Charts

C. *Process Control References* (Specifically note references that are the source of poor process control decisions or strategies, suspected or definitely identified)

D. Operations and Maintenance Manual

Manual Contents

Manual Located at Treatment Plant? Yes _____ No _____

Adequate Coverage? Yes _____ No _____

Operator/Manager Responsibilities Defined? Yes _____ No _____

Design Criteria Listed? Yes _____ No _____

Process Control Covered? Yes _____ No _____

Manual Used? Yes _____ No _____

Operating Staff

Specified in Manual? Yes _____ No _____

Present Staffing Meets/Exceeds Specified Staffing Requirement? Yes _____ No _____

Operator Qualifications

Specified in O&M Manual? Yes _____ No _____

Operator Possesses Specified Qualifications? Yes _____ No _____

Certification? Yes _____ No _____

Experience? Yes _____ No _____

Comments:

E. Pretreatment Program

Is There An Active Pretreatment Program? Yes ____ No ____

Significant Industries

Problems

Staffing

Sampling Frequency (announced? unannounced?)

Comments

F. Sewer Use Ordinance

Are There Problems At The Plant Related to Wastewater Influent?

Does The Ordinance Contain Provisions Necessary To Solve The Problem?

Is The Sewer Use Ordinance Being Enforced?

Comments:

G. *Laboratory Capability*

Facilities

	Adequate (Yes/No)	Comments
Bench Space		
Storage Space		
Floor Area		
Lighting		
Electricity		
Potable Water Supply		
Compressed Air		
Vacuum		
Chemical Fume Hood		
Air Conditioning		
Desk		
Records Storage		

Equipment and Instruments

	Available (Yes/No)	Comments
Portable DO Meter		
Settleometer		
Graduated Cylinder		
Turbidimeter		
Core Sampler (Sludge Depth)		
pH Meter		
Centrifuge		
Distilled Water (Source)		
BOD Incubator		
TSS Drying Oven		
FC Water Bath Incubator		
Hot Air Oven		
Refrigerator		
Autoclave		
Analytical Balance		
Microscope		
Desiccator		
Automatic Samplers		

G. Laboratory Capability (continued)

Analytical Capabilities

	Available (Yes/No)	Method/Comments
Total Solids		
TSS		
VSS		
Volatile Acids		
Alkalinity		
Temperature		
pH		
Turbidity		
BOD		
COD		
TKN		
Ammonia		
NO_2-NO_3-N		
Total Phosphorus		
Total Coliform		
Fecal Coliform		
Oxygen Uptake Rate (OUR)		
Specific OUR		

Miscellaneous

Quality Control

EPA Reference Samples

Duplicate Tests (schedule, records, etc.)

Other

Standard Procedures/References

Standard Methods

Site-Specific Procedures

Training

Form D-5
Maintenance Data

A. Preventive Maintenance Program

Program Description

Method of Scheduling

Method of Documenting Work Completed

Small Spare Parts (fuses, belts, bearings, packing diffusers, etc.)

Major Spare Parts (large motors, gear boxes, blowers, flowmeter, etc.)

References
O&M Manual

Accurate As-Builts

Manufacturers' Literature

Adequacy of Resources Available
Outside Support

Tools/Lubricants

Work Area

B. Emergency Maintenance Program

Priority Setting (relationship to process control decisions)

Expertise
On-Site

Technical Support

Method of Initiating Work Activities (work order?)

Method of Documenting Work Completed

Control Parts Procurement (policy restrictions? sources?)

Comments

C. General

Housekeeping

Method Of Factoring Costs For Parts/Equipment Into Budgeting Process

Equipment Age

Equipment Accessibility for Maintenance

Equipment or Processes Out of Service Due to Breakdowns (identify equipment or process, description of problem, length of time out of service, what has been done, what remains to be done, estimated time before repair, how it affects performance)

During the CPE (list and explain)

During the last 12 months (list and explain)

Form D-6
Performance Data

A. *Source of Data*

B. Reported Monitoring Data for Previous 12 Months (flows in mgd; others in mg/l, except as noted)

	Raw						Primary Effluent				
Mo/Yr	Flow	BOD_5	TSS				BOD_5	TSS			
AVG											

B. *Reported Monitoring Data for Previous 12 Months* (flows in mgd; others in mg/l, except as noted)

	Final Effluent						Other				
Mo/Yr	Flow	BOD$_5$	TSS	____	____	____	BOD$_5$	TSS	____	____	____
AVG											

Influent Quality Control Checks

Population:

Per Capita BOD$_5$ Contribution (0.17-0.22 lb/capita typical):

Service Taps:

Persons per Tap (2-4 typical):

C. Selected Plant Data for Previous 12 Months

Parameter	____	____	____	____	____	____	____	____	____
Units	____	____	____	____	____	____	____	____	____
Mo/Yr	____	____	____	____	____	____	____	____	____
____	____	____	____	____	____	____	____	____	____
____	____	____	____	____	____	____	____	____	____
____	____	____	____	____	____	____	____	____	____
____	____	____	____	____	____	____	____	____	____
____	____	____	____	____	____	____	____	____	____
____	____	____	____	____	____	____	____	____	____
____	____	____	____	____	____	____	____	____	____
____	____	____	____	____	____	____	____	____	____
____	____	____	____	____	____	____	____	____	____
____	____	____	____	____	____	____	____	____	____
____	____	____	____	____	____	____	____	____	____
____	____	____	____	____	____	____	____	____	____
AVG	____	____	____	____	____	____	____	____	____

D. *Permit Performance Violations Within Last 12 Months* (30-day averages, 7-day averages, instantaneous violations, effluent mass violations, percent removal violations)

E. *Reasons* (if any) ***Reported Monitoring Data Are Not Believed to Represent Actual Effluent Quality*** (unrepresentative sampling, improper lab analyses, selective reporting, unaccounted-for sludge loss [see attached sludge accountability evaluation], etc.)

F. Performance Monitoring/Sludge Accountability Summary Sheet

1. Sludge Accountability

Item

- Anticipated Sludge Production (see Table 2-7; Note: unit production values include solids lost in plant effluent) ____________lb/yr **1**
- Accounted-For Sludge

  - wasted intentionally ____________lb/yr **2**

  - effluent sludge ____________lb/yr **3**

  Total: **2** + **3** ____________lb/yr **4**

- Unaccounted-For Sludge: **1** - **4** ____________lb/yr **5**

  5 ÷ 365 ____________lb/d **6**

- Unaccounted-For Sludge Percentage: 100 x **5** ÷ **1** ____________% **7**

  if -15 < **7** < 15 then not possible to conclude that a problem with sludge wasting exists.

  if **7** > 15 then problem with effluent monitoring indicated.

  if **7** < -15 then may indicate organic loading greater than typical domestic (i.e., industrial loading).

2. Performance Monitoring Assessment

- Projected Acutual Effluent TSS

  - recorded effluent TSS ____________mg/l **8**

  - projected increase in effluent TSS: **6** ÷ (8.34 x flow in mgd) ____________mg/l **9**

  - estimated actual effluent TSS: **8** + **9** ____________mg/l

- Projected Actual Effluent BOD_5

  - recorded effluent BOD_5 ____________mg/l **10**

  - projected increase in effluent BOD_5: 0.5 x **9** ____________mg/l **11**

  - estimated actual effluent BOD_5: **10** + **11** ____________mg/l

Form D-7
Interview Data

A. Interview Concerns

Interviews are used to obtain feedback in the four categories of administration, design, operation, and maintenance. The following items are presented to assist the interviewers in obtaining this feedback.

1. Administration

Owner Responsibility?
- Attitude toward staff?
- Attitude toward regulatory agency?
- Self-sustaining facility attitude?
- Attitude toward consultants?
- Policies?
- Communications (Formal/Informal)?

Performance Goal
- Is plant in compliance?
- If yes, what is making it that way?
- If no, why not?
- Is regulatory pressure felt for performance?
- What are performance requirements?
- What is stated performance goal?

Administrative Support
- Budget
  - Within range of other plants?
  - "Drained" to general fund?
  - Unnecessary expenditures?
  - Sufficient?
- Attitude toward rates?

Sewer Use Ordinance/Pretreatment Programs
- Available?
- Enforced?

Personnel
- Within range of other plants?
- Allows adequate time?
- Motivation, pay/comparison with other munbicipal units, supervision, working conditions?
- Productivity?
- Turnover?
- Training Support?

Involvement
- Visits to treatment plant?
- Awareness of facility?
- Request status reports (performance and cost-related)?
- Familiarity with plant needs?

2. Design

- Influent problems?
- Equipment problems?
- Status of warranties?
- Return process streams?
- Preliminary treatment?
- Secondary treatment?
- Disinfection?
- Advanced waste treatment?
- Sludge handling and disposal?
- Flow measurement?
- Flow splitting?
- Alarms or alternate power?

3. Operation

- Communication of decisions?
- Key control parameters?
- Involvement of staff?
- Laboratory quality?
- Administrative support?
- Staffing?
- Performance problems?
- Unit process optimization?
- External support?
- Process control testing/adjustments?
- O & M Manual/references?

4. Maintenance

- How are priorities set?
- Attitude toward program?
- Emergency versus preventive?
- Reliability? (spare parts or critical part procurement)
- Staffing?
- Equipment assessibility?

B. Personnel Interviews

Name ____________________

Title ____________________

Certification ____________________

Years at Plant ____________________ Years Experience ____________________

Area of Responsibility ____________________

Education ____________________

Training ____________________

Concerns/Recommendations (Administration, Design, Operation, Maintenance):

Appendix E

Procedures for Converting Oxygenation Rates and Flows

Procedures for Converting Standard Oxygenation Rates to Actual Oxygenation Rates

$$\mathrm{AOTR} = \mathrm{SOTR}\,(\alpha)\left[\frac{\beta C_{sw} - C_L}{C_s}\right] e^{(T-20)}$$

or

$$\mathrm{AOTE} = \mathrm{SOTE}\,(\alpha)\left[\frac{\beta C_{sw} - C_L}{C_s}\right] e^{(T-20)}$$

Where:

AOTR = actual oxygen transfer rate, lb O_2/hp-hr.

AOTE = actual oxygen transfer efficiency, percent.

SOTR = standard oxygen transfer rate, lb O_2/hp-hr (from Table 2-3).

SOTE = standard oxygen transfer efficiency, percent (from Table 2-3).

α = relative rate of oxygen transfer in wastewater compared to water. Estimate from Table E-1.

β = relative oxygen saturation value in wastewater compared to water. Estimate $\beta = 0.95$ for mixed liquor.

θ = temperature correction constant, $\theta = 1.024$.

C_s = Oxygen saturation value of clean water at standard conditions, $C_s = 9.17$ mg/L.

C_{sw} = oxygen saturation value of clean water at site conditions of temperature and pressure, mg/L.

$$C_{sw} = C_{14.7}\left[\frac{P}{14.7}\right]$$

C_L = mixed liquor DO concentration, mg/L.

T = temperature of the liquid, °C.

$C_{14.7}$ = oxygen saturation value of clean water at standard pressure of 14.7 psi and actual water temperature (see Table E-2).

P = actual pressure at oxygen transfer point.

a) For surface aerators, use atmospheric pressure (see Figure E-1).

b) For others, use atmospheric pressure from Figure E-1, plus the pressure at one-third depth of the tank from the surface to the diffusers (i.e., diffuser depth in feet x 0.33 x 0.434 psi/ft). [NOTE: The one-third depth is an approximation. Actual pressure at oxygen transfer point may vary depending on such factors as type of diffusers and tank geometry. To be more conservative, utilize atmospheric pressure.]

Procedure for Converting Actual (or Inlet) CFM to Standard CFM

$$\mathrm{ACFM} = \mathrm{SCFM}\left[\frac{T_a}{T_s}\right]\left[\frac{P_s}{P_a}\right]$$

Where:

ACFM = volume of air measured at actual site conditions of elevation and maximum summertime air temperature.

SCFM = volume of air measured at standard conditions of 14.7 psia and 20°C.

T_a = maximum summertime inlet temperature, °R [NOTE: °R = °F + 460].

T_s = standard inlet temperature, °R.

P_a = inlet pressure to blower at site conditions, psia (see Figure E-1).

P_s = inlet pressure to blower at standard conditions, 14.7 psia.

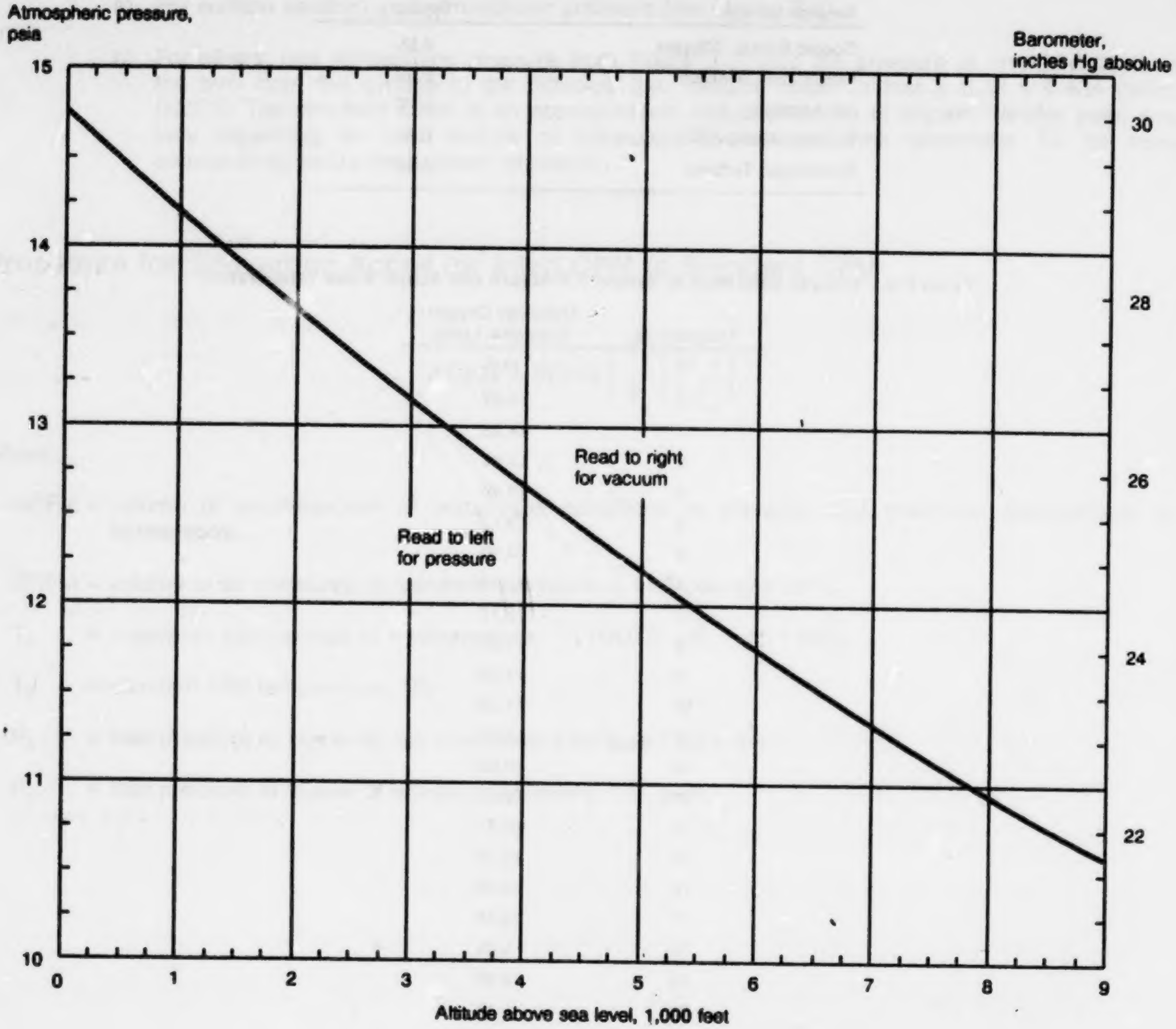
Table E-1. Typical Values of Alpha (α) Used For Estimating AOTR/SOTR

Aeration Device	Typical α
Coarse Bubble Diffusers	0.85
Fine Bubble Diffusers	0.50
Jet Aeration	0.75
Surface Mechanical Aerators	0.90
Submerged Turbines	0.85

Table E-2. Oxygen Saturation at Standard Pressure and Actual Water Temperature

Temperature	Dissolved Oxygen Saturation Level
°C	mg/l
0	14.62
1	14.23
2	13.84
3	13.48
4	13.13
5	12.80
6	12.48
7	12.17
8	11.87
9	11.59
10	11.33
11	11.09
12	10.83
13	10.60
14	10.37
15	10.15
16	9.95
17	9.74
18	9.54
19	9.35
20	9.17
21	8.99
22	8.83
23	8.68
24	8.53
25	8.38
26	8.22
27	8.07
28	7.92
29	7.77
30	7.63

Figure E-1. Atmospheric pressure at various altitudes.



Appendix F

Guidelines for Field Estimating Equipment Power Usage

The power that a particular piece of equipment is drawing can be estimated in the field by measuring the current being drawn by the motor. The measured power being drawn by a motor (inductive user) is "apparent power" and must be multiplied by the power factor (PF) to calculate actual power. Four methods are available to arrive at a suitable power factor:

1. Assume a power factor:

   Use 0.9 for recently constructed plants that likely included use of capacitors to adjust the power factor toward 1.0. Use 0.75 for old and small plants where it is unlikely that capacitors have been added.

2. Measure the "plant power factor" using an ammeter and the plant kilowatthour meter and assume the power factor applies for larger pieces of equipment. See Table F-1 for calculation worksheet. **(WARNING: DO NOT USE THIS METHOD UNLESS QUALIFIED.)**

3. Ask the electric company to measure the power factor or actual power usage of specific equipment.

4. Rent an appropriate instrument and measure power factor or actual power usage. **(WARNING: DO NOT USE THIS METHOD UNLESS QUALIFIED.)**

Once the PF has been determined, the following calculations can be used to estimate power drawn by a particular piece of equipment:

Measure:

Average Voltage (line-to-line) = ______________Volts

Average Amperage = ______________Amps

Calculate:

kVA = V x A x $(3)^{1/2}$ ÷ 1,000 (3-phase power)

kW = kVA x PF

whp = kW ÷ 0.746

Table F-1. Worksheet for Calculation of Power Factor

Apparent Power

Line-to-Line Voltage on Incoming Power:

$V_{1\text{-}2}$ = ________________ Volts

$V_{2\text{-}3}$ = ________________ Volts

$V_{1\text{-}3}$ = ________________ Volts

V_{avg} = ________________ Volts

Amperage for Each Phase on Incoming Power:

I_1 = ________________ Amps

I_2 = ________________ Amps

I_3 = ________________ Amps

I_{avg} = ________________ Amps

kVA = Volts x Amps x $(3)^{1/2}$ ÷ 1,000 = ________________

Actual Power

K_h = ________________ watthours/revolution (from meter)

CTR[a] = ________:________

PTR[b] = ________:________

TR[c] = CTR x PTR = ________________ x ________________ = ________________

Disc Speed = ________________ Seconds/ ________________ Revolutions(s)

kW = K_h x TR x (Disc Rev/sec) x (3,600 sec/hour) x (1 kW/1,000 Watts) = ________________

Power Factor

PF = kW ÷ kVA = ________________ ÷ ________________ = ________________

---

[a] CTR (Current Transformer Ratio) - ratio of primary to secondary current. For current transformer rated 200:5, ratio is 200/5 or 40/1.

[b] PTR (Potential Transformer Ratio) - ratio of primary to secondary voltage. For potential transformer rated 480:120, ratio is 480/120 or 4/1.

[c] TR (Tranformer Ratio) - total ratio of current and potential transformers. For CTR = 200:5 and PTR = 480:120, TR = 40 x 4 = 160.

Appendix G

Example Forms for Establishing a Preventive Maintenance Program for Small POTWs

Form	Title
G-1	Equipment Information Sheet
G-2	Daily Preventive Maintenance
G-3	Weekly Preventive Maintenance
G-4	Monthly Preventive Maintenance

Form G-1
Equipment Information Sheet

Plant Equipment Number ____________

Equipment: ______________________________

Location ____________________ **Original Installation Date** ____________

Manufacturer ____________ **Model** ________ **Serial No.** ____________

Type ________ **Rated Capacity** ________ **Rated Pressure or Head** ________

Additional Data ______________________________

____

Drive

Type ____________________ **Manufacturer** ____________________

Description ______________________________

____

Motor

Manufacturer ____________________ **HP** ____________ **RPM** ____________

Frame ____________ **Enclosure Type** ____________ **S.F.** ____________

Type ____________ **Rated Amperage** ____________ **Rated Voltage** ____________

Suppliers

Company Name & Address	**Contact Person**	**Telephone No.**

Additional Information and Comments

Form G-1 (continued)
Equipment Information Sheet

Recommended Preventive Maintenance

	Frequency

Recommended Lubricants

Part	Lubricant Name/Description	Source

Recommended Spare Parts

Part Description	Number	Quantity

Form G-2
Daily Preventive Maintenance

		Time	Initials
Inlet Building			
• Check operation of grit pump, cyclone, grit bin, pump seal water pressure _________ (psi), leakage _________ (drops/min)	a.m.	_________	_________
	p.m.	_________	_________
• Check grit collector for unusual noise or torque.	a.m.	_________	_________
	p.m.	_________	_________
• Check flow meter operation, chain, float, stilling well.	a.m.	_________	_________
	p.m.	_________	_________
• Check auto sampler operation and bottle installation.	a.m.	_________	_________
	p.m.	_________	_________
Grit Separator #2 Building			
• Check for unusual noise or vibration in collector or conveyer.	a.m.	_________	_________
	p.m.	_________	_________
Primary Clarifier			
• Check for unusual noise or vibration in drive unit.	a.m.	_________	_________
	p.m.	_________	_________
Aeration Building			
• Check blowers for unusual noise or vibration. **Temperature** #1 Inlet ___________ °C Outlet ___________ °C #2 Inlet ___________ °C Outlet ___________ °C #3 Inlet ___________ °C Outlet ___________ °C	a.m.	_________	_________
	p.m.	_________	_________
• Check auto sampler operation and bottle installation	a.m.	_________	_________
	p.m.	_________	_________

(Form continued to include all process units and buildings requiring daily maintenance.)

Form G-3
Weekly Preventive Maintenance

	Date	Initials
Inlet Building		
• **Grit #1 Collector Drive:** Apply grease to upper and lower bearings in worm gear housing.	______	______
• **Grit #1 Collector Drive:** Check oil level in gear housing; remove condensate in gear drive.	______	______
• **Grit #1 Collector Drive:** Lubricate chain between drive unit and motor gear.	______	______
• **Grit #1 Collector Drive:** Check torque overload alarm for proper operation.	______	______
• **Comminutor:** Check oil level in main gear box (lower).	______	______
• **Comminutor:** Check oil level in motor gear unit.	______	______
• **Automatic Sampler:** Remove and clean sampling tube and strainer.	______	______
Grit Separator #2 Building		
• **Grit #2 Drive Unit:** Check oil level in Philadelphia gear reducer.	______	______
• **Grit #2 Conveyor Unit:** Apply grease to all bearings of chain drive and support sprockets.	______	______
• **Grit #2 Conveyor Unit:** Check oil level in conveyor drive reducer.	______	______
Aeration Building		
• **Automatic Sampler:** Remove and clean sampling tube and strainer.	______	______
• **Aeration Blowers:** Check oil level - 3 points (gears, two bearings).	______	______
• **Aeration Blowers:** Operate blower(s) (10-min each) not in service. Check oil level and temperature.	______	______

(Form continued to include all process units and buildings requiring daily maintenance.)

Form G-4
Monthly Preventive Maintenance

	Date	Initials
Inlet Building		
• **Automatic Sampler:** Check pump tubing for signs of failure. Remove from pump housing to inspect.	________	________
Grit Separator #2 Building		
• **Grit Reducer:** Apply grease to upper and lower bearings.	________	________
Primary Clarifier		
• **Drive Mechanism:** Check gear lubrication (dipstick). Check base plate lubrication (oil cap).	________	________
• **Gear Reducer:** Apply grease to upper, lower, and two side bearings.	________	________

(Form continued to include all process units and buildings requiring daily maintenance.)

Provide similar forms for:

- **Quarterly Preventive Maintenance**
- **Semiannual Preventive Maintenance**
- **Annual Preventive Maintenance**

Appendix H

Example Wastewater Treatment Plant Administration and Management Audit

PLANT: ______________________

DEPARTMENT (circle one)

Administration (off-site)
Administration (on-site)
Operation
Maintenance
Laboratory

IMMEDIATE SUPERVISOR ______________________

DATE ______________________

Instructions

Listed below are several questions that will be used to help assess existing conditions. By answering these questions you can provide helpful feedback to the management and administration and indicate areas where you feel changes could improve conditions, areas that you feel need enhancement, or areas where you want to support present conditions. Your answers are confidential. Please circle the number you think best describes your opinion. If you want to clarify a point, please do so in the space immediately below each question. If you need more room, reference the question number and use another sheet of paper or the back of the page. Thank you for your cooperation and support.

1. **In your present position, how adequate is your pay (compensation including benefits)?** (1 is very poor, 5 is average, and 10 is excellent)

1 2 3 4 5 6 7 8 9 10

2. **Relative to your immediate supervisor, please rate the following factors.** (1 is poor, 5 is average, and 10 is high)

A. Technical capability	1	2	3	4	5	6	7	8	9	10
B. Ability to recognize problems and set priorities	1	2	3	4	5	6	7	8	9	10
C. Ability to conduct staff meetings	1	2	3	4	5	6	7	8	9	10
D. Ability to discuss job-related ideas or problems	1	2	3	4	5	6	7	8	9	10
E. Ability to follow through with decisions on tasks	1	2	3	4	5	6	7	8	9	10
F. Use of staff suggestions	1	2	3	4	5	6	7	8	9	10
G. Ability to motivate staff	1	2	3	4	5	6	7	8	9	10
H. Provide recognition for a job well done	1	2	3	4	5	6	7	8	9	10
I. Fairness	1	2	3	4	5	6	7	8	9	10
J. Communication skills	1	2	3	4	5	6	7	8	9	10

3. **What is your potential for continuing employment with the City for more than 3 years?** (1 is definitely no potential, 5 is possible potential, and 10 is definite potential)

1 2 3 4 5 6 7 8 9 10

4. **What is the adequacy of the number of staff members in your department?** (1 is very inadequate, 5 is adequate, and 10 is more than adequate)

1 2 3 4 5 6 7 8 9 10

5. **How adequate are the benefits (i.e., sick leave, vacation, insurance, etc.) provided by the City?** (1 is very poor, 5 is average, and 10 is very good)

1 2 3 4 5 6 7 8 9 10

6. **What is the level of productivity (efficiently getting things done) on the staff?** Please rate each "department" that you are familiar with. (1 is low, 5 is average, and 10 is high)

A. Laboratory	1	2	3	4	5	6	7	8	9	10
B. Maintenance	1	2	3	4	5	6	7	8	9	10
C. Administration (off-site)	1	2	3	4	5	6	7	8	9	10
D. Administration (on-site)	1	2	3	4	5	6	7	8	9	10
E. Operations	1	2	3	4	5	6	7	8	9	10

7. **Relative to supervisory personnel other than your immediate supervisor, how would you rate the following factors?** (1 is poor, 5 is average, and 10 is high)

A. Technical capability	1	2	3	4	5	6	7	8	9	10
B. Ability to recognize problems and set priorities	1	2	3	4	5	6	7	8	9	10
C. Ability to conduct staff meetings	1	2	3	4	5	6	7	8	9	10
D. Ability to discuss job-related ideas or problems	1	2	3	4	5	6	7	8	9	10
E. Ability to follow through with decisions or tasks	1	2	3	4	5	6	7	8	9	10
F. Use of staff suggestions	1	2	3	4	5	6	7	8	9	10
G. Ability to motivate staff	1	2	3	4	5	6	7	8	9	10
H. Provide recognition for a job well done	1	2	3	4	5	6	7	8	9	10
I. Fairness	1	2	3	4	5	6	7	8	9	10
J. Communication skills	1	2	3	4	5	6	7	8	9	10

8. **Is it clear to you as to what is expected of you in your current position?** (1 is very unclear, 5 is clear, and 10 is very clear)

1 2 3 4 5 6 7 8 9 10

9. **What is the level of the staff morale?** Please rate your "department" and any other "departments" that you have an opinion of. (1 is low, 5 is medium, and 10 is high)

A. Laboratory	1	2	3	4	5	6	7	8	9	10
B. Maintenance	1	2	3	4	5	6	7	8	9	10
C. Administration (off-site)	1	2	3	4	5	6	7	8	9	10
D. Administration (on-site)	1	2	3	4	5	6	7	8	9	10
E. Operations	1	2	3	4	5	6	7	8	9	10

10. **How consistently do fellow staff/shift personnel implement daily routines, tasks, or tests (e.g., does previous shift perform all required duties)?** (1 is never consistent, 5 is consistent most of the time, and 10 is always consistent)

1 2 3 4 5 6 7 8 9 10

11. **How adequate is the equipment (i.e., tools, trucks, typewriters, computers, etc.)?** (1 is very inadequate, 5 is satisfactory, and 10 is very adequate)

1 2 3 4 5 6 7 8 9 10

12. **What is the qualification level (i.e., education or training) of the staff members you directly work with?** (1 is poorly qualified, 5 is average, and 10 is highly qualified)

1 2 3 4 5 6 7 8 9 10

13. **To what degree is there a spirit of teamwork or cooperation between staff members in your "department"?** (1 is very poor, 5 is average, and 10 is a high degree of cooperation)

1 2 3 4 5 6 7 8 9 10

14. **What is the adequacy of the physical environment you work in (i.e., appearance, safety, cleanliness, lighting, etc.)?** (1 is very poor, 5 is average, and 10 is very good)

1 2 3 4 5 6 7 8 9 10

15. **Do you use a data-based (i.e., use results of analyses, calculations, trend charts, etc.) decision-making process in optimizing treatment plant performance?** (1 is never used, 5 is used for some decisions, and 10 is always used)

1 2 3 4 5 6 7 8 9 10

16. **How well does the management or City administration keep the staff informed of existing policies, new policies, or other current events that you feel should be disseminated?** (1 is very poor, 5 is average, and 10 is very well)

1 2 3 4 5 6 7 8 9 10

17. **To what degree is there a spirit of cooperation between different "departments"?** (1 is very poor, 5 is average, and 10 is a high degree of cooperation)

1 2 3 4 5 6 7 8 9 10

18. **How do you rate the treatment plant staff in terms of being well organized?** (1 is very low, 5 is average, and 10 is very high)

1 2 3 4 5 6 7 8 9 10

19. **How do you rate the treatment plant staff in terms of communications?** (1 is very low, 5 is average, and 10 is very high)

1 2 3 4 5 6 7 8 9 10

20. **Are you challenged in your present position?** (1 is not challenged, 5 is average, and 10 is very challenged)

1 2 3 4 5 6 7 8 9 10

List any suggestions you have that would improve overall performance of the treatment plant. Please be specific.

What are your goals?

Appendix I

Example Process Monitoring Summary for an Activated Sludge POTW

Daily Control Calculation Sheet for an Activated Sludge POTW[a]

Aerator Volume (AV) = ______________ m^3 Clarifier Depth (CD) = ______________ m
Clarifier Volume (CV) = ______________ m^3 Clarifier Surface Area (CSA) = ______________ m^2 Location ______________________________ Month/Year ____________

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
DATE	ATC (%)	RSC (%)	CSC (%)	DOB (m)	TURB (NTU)	FLOW (m^3/d)	RSF (m^3/d)	RFP (%)	RSP (%)	ASU (m^3x%)	CSU (m^3x%)	SDR (ASU/CSU)	TSU (m^3x%)	ESU (m^3x%)	XSU (m^3x%)	WSU (m^3x%)	MCRT (d)	RSU (m^3x%)	SDT_A (hr)	SDT_C (hr)	SDT_AxATC (hrx%)	CSL (units/m^2)	OFR (m^3/m^2/d)	SSC_5 (%)	SSC_{60} (%)
1																									
2																									
3																									
4																									
5																									
6																									
7																									
8																									
9																									
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29																									
30																									
31																									
TOT																									
AVG																									

[a] See following page for an explanation of symbols used on this sheet.

Column Information for Daily Control Calculation Sheet

Column	Symbol	Symbol Meaning	Explanation
1	DATE	Self explanatory	
2	ATC	Aeration Tank Concentration	Average of values recorded during the day on the Daily Data Sheet.
3	RSC	Return Sludge Concentration	Average of values recorded during the day on the Daily Data Sheet.
4	CSC	Clarifier Sludge Concentration	Average concentration of sludge within the clarifier as determined from a core sample (Method 1) or by calculation (Method 2). Method 1. Core Sample - average of values recorded during the day on the Daily Data Sheet. Method 2. Calculation - average of ATC and RSC. CSC = (ATC + RSC) ÷ 2
5	DOB	Depth of (Sludge) Blanket	Average of values recorded during the day on the Daily Data Sheet.
6	TURB	Turbidity	Average of values recorded during the day on the Daily Data Sheet.
7	FLOW	Daily Wastewater Flow	Total wastewater flow for a given 24-hour time period (e.g., 8:00 a.m. to 8:00 a.m.).
8	RSF	Return Sludge Flow	Total daily return sludge flow. [Note: Time period for determining this rate should be the same as the time period used for determining daily wastewater flow rate (e.g., 8:00 a.m. to 8:00 a.m.)].
9	RFP	Return Sludge Flow Percentage	Return sludge flow divided by average daily wastewater flow. RFP = (RSF ÷ FLOW) x 100
10	RSP	Return Sludge Percentage	Return sludge flow percentage based on mass balance. RSP = 100 x [(ATC) ÷ (RSC - ATC)]
11	ASU	Aerator Sludge Units	Total aeration tank volume (AV) times ATC.
12	CSU	Clarifier Sludge Units	Method 1. Core Sample - clarifier sludge concentration times the clarifier volume (CV). CSU = CSC x CV Method 2. Calculation - clarifier sludge concentration times the fraction of the clarifier filled with sludge, times the clarifier volume (CV). CSU = CSC x [(DOB)/(CD)] x CV
13	SDR	Sludge Distribution Ratio	Ratio of the quanitity of solids under aeration vs. the quantity of solids in the clarifier. SDR = ASU ÷ CSU
14	TSU	Total Sludge Units	TSU = ASU + CSU
15	ESU	Effluent Sludge Units	Quantity of sludge lost in the effluent each day. ESU = Effluent suspended solids (TSS) times FLOW divided by ratio of MLSS to percent solids by centrifuge (e.g., ratio = MLSS divided by ATC). ESU = (TSS x FLOW) ÷ Ratio
16	XSU	Intentionally Wasted Sludge Units	Quantity of sludge intentionally wasted from the system each day = average concentration of wasted sludge times the volume of sludge wasted (from the Daily Data Sheet).
17	WSU	Total Waste Sludge Units	WSU = ESU + XSU
18	MCRT	Mean Cell Residence Time	Average number of days a given quantity of sludge remains in the system. MCRT = TSU ÷ WSU
19	RSU	Return Sludge Units	Return sludge flow rate times the return sludge concentration. RSU = RSF x RSC
20	SDT_A	Sludge Detention Time in the Aerator	Average number of hours a given quantity of sludge remains in the aerator. SDT_A = (AV x 24 hr/d) ÷ (FLOW x RSF)
21	SDT_C	Sludge Detention Time in the Clarifier	Average number of hours a given quantity of sludge remains in the clarifier. SDT_C = (CSU x 24 hr/d) ÷ RSU

Column Information for Daily Control Calculation Sheet (continued)

Column	Symbol	Symbol Meaning	Explanation
22	SDT_A x ATC	See meanings above.	Indication of the treatment pressure in the system.
23	CSL	Clarifier Solids Loading	Average daily mass of sludge to the clarifier divided by the clarifier surface area (CSA). CSL = [(FLOW + RSF) (ATC)] ÷ CSA
24	OFR	Clarifier Surface Overflow Rate	Upward velocity of the treated wastewater in the secondary clarifier. OFR = FLOW ÷ CSA
25	SSC_5	Settled Sludge Concentration in 5 Minutes	Average of values recorded during the day on the Daily Data Sheet.
26	SSC_{60}	Settled Sludge Concentration in 60 Minutes	Average of values recorded during the day on the Daily Data Sheet.

Appendix J

Example Process Monitoring Summary for an RBC POTW

Example RBC Process Monitoring Summary

Plant Name: ____________________

Week of ____________________ 19____

Day	Sun	Mon	Tues	Wed	Thur	Fri	Sat	Weekly Average
Date								
Flow, m^3/d								
Influent								
BOD$_5$, mg/L								
SBOD$_5$, mg/L								
TSS, mg/L								
pH, units								
Temperature, °C								
Wet Well								
SBOD$_5$, mg/L								
Primary Clarifier								
DOB*, m								
BOD$_5$, mg/L								
SBOD$_5$, mg/L								
TSS, mg/L								
pH, units								
Temperature, °C								
Secondary Clarifiers								
DOB$_1$, m								
DOB$_2$, m								
BOD$_5$, mg/L								
SBOD$_5$, mg/L								
Chlorine Contact Effluent								
Cl$_2$ residual, mg/L								
Fecal Coliform, MPN/liter								GM*
pH, units								
TSS, mg/L								
O & G*, mg/L								
Secondary Sludge								
min/d pumped								
liter/s								
m^3/d								
spin*, percent								
ratio*								
mg/L								
kg/d								
Primary Sludge								
Start time								
End time								
Minutes								
m^3/d								
m^3								
spin., percent								
ratio								
mg/L								
kg/d								

Example RBC Process Monitoring Summary (continued)

RBC Dissolved Oxygen

(Date ________ Time ________)

	Train 1	Train 2	Train 3
Stage 1	______	______	______
Stage 2	______	______	______
Stage 3	______	______	______
Stage 4	______	______	______

RBC Train Performance

(Date ________ Time ________)

$SBOD_5$

Train 1 ________ mg/l

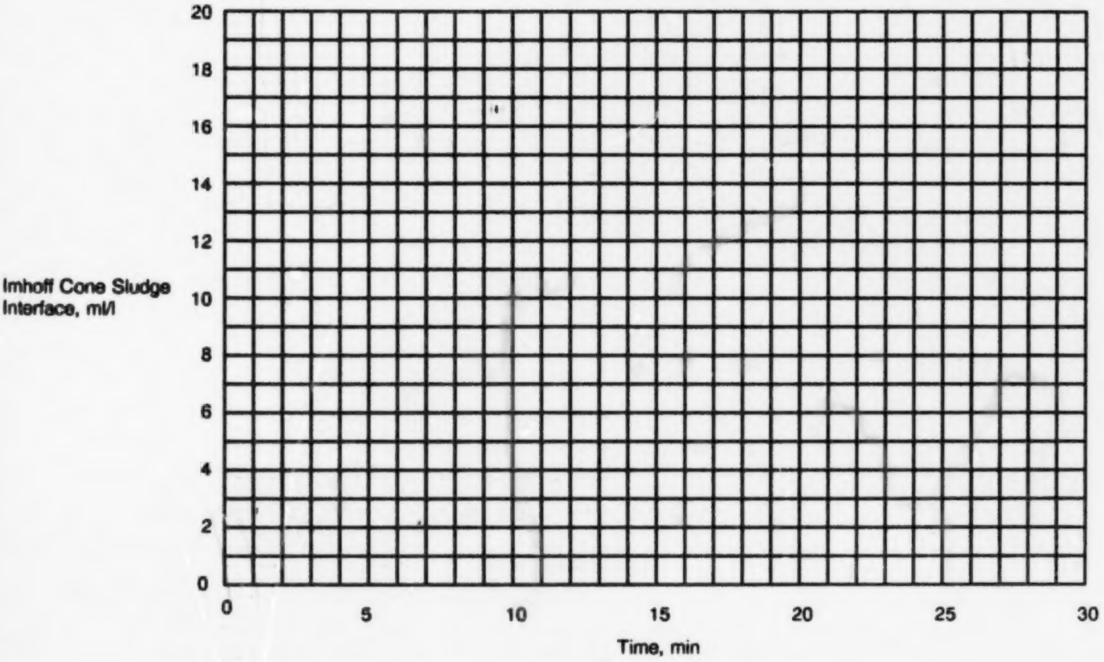
Train 2 ________ mg/l

Train 3 ________ mg/l

RBC Effluent

(Date ________ Time ________)

DO ________ mg/l TSS ________ mg/l pH ________ Temp ________ °C



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* DTB	Depth of (sludge) Blanket
GM	Geometric Mean
O & G	Oil and Grease
SPIN	Concentration; percent of sample volume the compacted sludge occupies after a 15-minute laboratory centrifuge spin
RATIO	MLSS divided by ATC (see Appendix I, Column Information for Daily Control Calculation Sheet)

Appendix K
Parameters Used to Monitor the ABF Treatment Process

Parameters Used to Monitor the ABF Treatment Process

Column	Symbol	Symbol Meaning	Explanation
1	DATE	Self Explanatory	
2	ATC	Aeration Tank Concentration	Average of values recorded during the day on the Daily Data Sheet.
3	RSC	Return Sludge Concentration	Average of values recorded during the day on the Daily Data Sheet.
4	CSC	Clarifier Sludge Concentration	Average concentration of sludge within the clarifier. Average of values recorded during the day on the Daily Data Sheet.
5	DOB	Depth to (Sludge) Blanket	Average of values recorded during the day on the Daily Data Sheet.
6	TURB	Turbidity	Average of values recorded during the day on the Daily Data Sheet.
7	FLOW	Daily Wastewater Flow	Total wastewater flow for a given 24-hour time period (e.g., 8:00 a.m. to 8:00 a.m.).
8	RSF	Return Sludge Flow	Total daily return sludge flow. [Note: Time period for determining this rate should be the same as the time period used for determining daily wastewater flow rate (e.g., 8:00 a.m. to 8:00 a.m.)].
9	RFP	Return Sludge Flow Percentage	Return sludge flow divided by average daily wastewater flow. RFP = (RSF ÷ FLOW) x 100
10	BCRF	Biocell Direct Recirculation Flow	Daily total flow from the biocell under drain directly to the recirculation wet well. (Note: Time period for determining this flow should be the same as for determining the average daily wastewater flow.)
11	BCRFP	Biocell Direct Recirculation Flow Percentage	Percentage expression of the ratio of the volume of direct biocell recirculation to the volume of raw wastewater. BCRFP = (BCRF ÷ FLOW) x 100
12	TFBC	Total Flow to the Biocell	Total volume of liquid pumped to the biocell. TFBC = FLOW + RSF + BCRF
13	BCHL	Biocell Hydraulic Load	Volume of liquid pumped to the biocell per unit area of biocell in operation. (TFBC x 695) ÷ Biocell Surface Area
14	ASU	Aerator Sludge Units	Total aerator volume (AV) times ATC.
15	CSU	Clarifier Sludge Units	Clarifier volume (CV) times clarifier sludge concentration. CSU = CV x CSC
16	TVBC	Total Volume in the Biocell	Volume of mixed liquor in the biocell and associated appurtenances. TVBC = volume in tower, volume in underdrain, volume in recirculation, and volume in tower piping.
17	BCSU	Biocell Sludge Units	BCSU = TVBC x ATC
18	TSU	Total Sludge Units	TSU = ASU + BCSU + CSU
19	SDR	Sludge Distribution Ratio	Ratio of the mass of solids in the aeration tank + mass of sludge in the biocell to the mass of sludge in the final clarifier. SDR = (ASU + BCSU) ÷ CSU
20	ESU	Effluent Sludge Units	Quantity of sludge lost in the effluent each day. ESU = (TSS x FLOW) ÷ Ratio Ratio = MLSS ÷ ATC
21	XSU	Intentionally Wasted Sludge Units	Quantity of sludge intentionally wasted from the system each day = average concentration of wasted sludge times the volume of sludge wasted (from the Daily Data Sheet).
22	WSU	Total Waste Sludge Units	WSU = ESU + XSU
23	MCRT	Mean Cell Residence Time	Average of number of days a given quantity of sludge remains in the system. MCRT = TSU ÷ WSU
24	RSU	Return Sludge Units	Return sludge flow rate times the return sludge concentration. RSU = RSF x RSC

A Daily Control Calculation Sheet similar to the one presented for activated sludge in Appendix I can be used to present these parameters in tabular form.

Parameters Used to Monitor the ABF Treatment Process (continued)

Column	Symbol	Symbol Meaning	Explanation
25	SDT_A	Sludge Detention Time in the Aerator	Average number of hours a given quantity of sludge remains in the aerator. SDT_A = (AV x 24 hr/d) ÷ (TFBC - BCRF)
26	SDT_{BC}	Sludge Detention Time in the Biocell	Average number of hours a given quantity of sludge remains in the clarifier. SDT_{BC} = TVBC ÷ TFBC
27	SDT_C	Sludge Detention Time in the Biocell	Average number of hours a given quantity of sludge remains in the clarifier. SDT_C = CSU ÷ RSU
28	TDT	Total Detention Time	TDT = SDT_A + SDT_{BC} + SDT_C
29	CYCLES	Sludge Cycles per Day	Number of times the sludge cycles through the entire system during the day. CYCLES = (24 hr/d) ÷ TDT
30	SDT_A x ATC	See meanings above.	Indication of the treatment pressure in the system.
31	CSL	Clarifier Solids Loading	Average daily mass of sludge to the clarifier divided by the clarifier surface area (CSA). CSL = [(TFBC - BCRF) (ATC)] ÷ CSA
32	OFR	Clarifier Surface Overflow Rate	Upward velocity of the treated wastewater in the secondary clarifier. OFR = FLOW ÷ CSA
33	SSC_5	Settled Sludge Concentration in 5 Minutes	Average of values recorded during the day on the Daily Data Sheet.
34	SSC_{30}	Settled Sludge Concentration in 30 Minutes	Average of values recorded during the day on the Daily Data Sheet.
35	SSC_{60}	Settled Sludge Concentration in 60 Minutes	Average of values recorded during the day on the Daily Data Sheet.
36	RSP	Return Sludge Percentage	Indication of return flow percentage thst is based on a solids balance. RSP = 100 x [(ATC) ÷ (RSC - ATC)]
37	OUR	Oxygen Uptake Rate	Average of values from the Daily Data Sheet.
38	WASTE	Waste Volume	Average of values from the Daily Data Sheet.
39	RECIRC	Recirculation Power	Average of values from the Daily Data Sheet.
40	AERATION	Aeration Blower Power	Average of values from the Daily Data Sheet.
41	WASTE	Waste Power	Average of values from the Daily Data Sheet.

Appendix L

Suspended Growth Major Unit Process Evaluation Worksheet

This worksheet is used to evaluate the capability of existing major unit processes, i.e., aerator, secondary clarifier, and sludge handling system. Key loading and process parameters are compared with standard values and point scores are assigned. These points are subsequently compared with expected point scores for Type 1, Type 2, and Type 3 facilities, and a determination of the plant Type is made.

Instructions for use:

- Proceed through the steps contained in this worksheet *in order*.
- Use actual values in lieu of calculations if such data are available and appear reliable, e.g., waste sludge volume.
- When assigning points, interpolate and use the nearest whole number.
- Minimum and maximum point values are indicated - do not exceed the range illustrated.

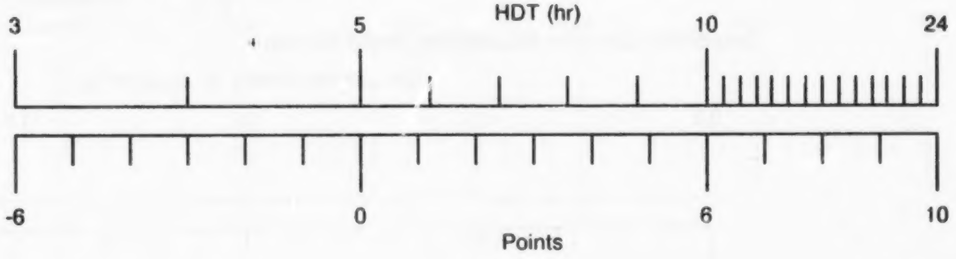
Aeration Basin

Calculate Hydraulic Detention Time (HDT):

$$\text{HDT} = \frac{\text{Aeration Basin Volume}}{\text{Peak Month Average Daily Flow}}$$

$$\text{HDT} = \frac{(\qquad\qquad \text{cu ft})}{(\qquad\qquad \text{gpd})} \times 180 = \underline{\qquad\qquad} \text{ hr}$$

Determine HDT Point Score:



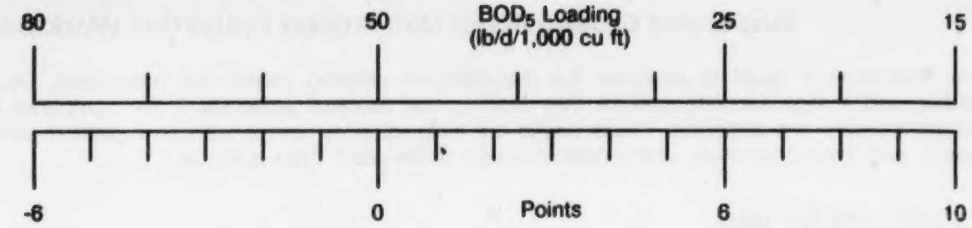
HDT Point Score **=** ________ ①

Calculate BOD_5 Loading:

$$BOD_5 \text{ Loading} = \frac{\text{Average Daily } BOD_5 \text{ Loading}}{\text{Aeration Basin Volume}}$$

$$BOD_5 \text{ Loading} = \frac{(\qquad\qquad \text{lb/d})}{(\qquad\qquad \text{cu ft})} \times 1000 = \underline{\qquad} \text{ lb } BOD_5\text{/d/1000 cu ft}$$

Determine BOD_5 Loading Point Score:



***BOD_5 Loading Point Score* = ________** ②

Calculate Oxygen Availability:

Mechanical Aeration Systems

If data are not available on oxygen transfer capacity, calculate it as Wire Horsepower (Appendix F) times Actual Oxygen Transfer Rate (Appendix E).

(________hp) x (________lb/hp-hr) x 24 = ________lb O_2/d

Diffused Air Aeration Systems

If data are not available on oxygen transfer capacity, calculate an actual oxygenation rate (Section 2.3.3.1).

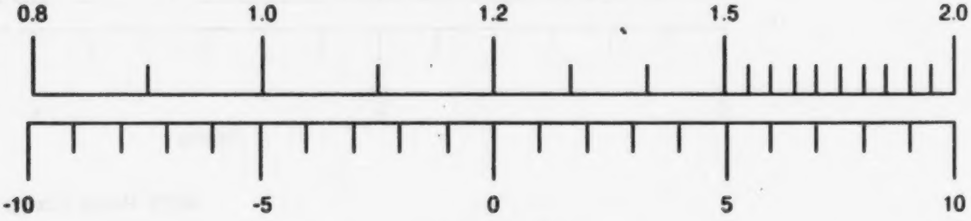
________lb O_2/d

$$\text{Oxygen Availability} = \frac{\text{Oxygen Transfer Capacity}}{BOD_5 \text{ Loading to Aerator}}$$

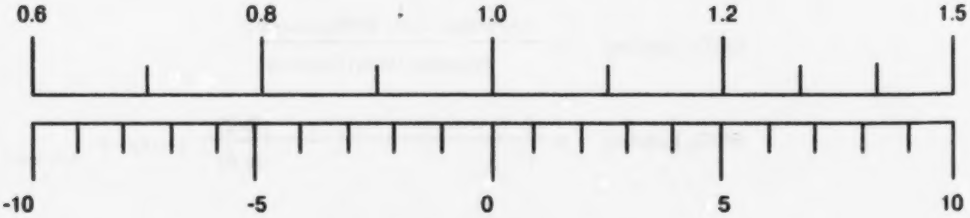
$$\text{Oxygen Availability} = \frac{(\qquad\qquad \text{lb/d})}{(\qquad\qquad \text{lb/d})} = \underline{\qquad\quad} \text{ lb } O_2/\text{lb } BOD_5$$

Determine Oxygen Availability Point Score:

Oxygen Availability (lb O_2/lb BOD_5)



with Nitrification



without Nitrification

Points

***Oxygen Availability Point Score* = ________** ③

Add Scores 1, 2, and 3 to Obtain Subtotal for Aeration Basin:

Aeration Basin Subtotal = ________ ④

Secondary Clarifier

Determine Clarifier Configuration Point Score:

Configuration	Points
Circular with "donut" or interior launders	10
Circular with weirs on walls	5
Rectangular with 33% covered with launders	5
Rectangular with 20% covered with launders	0
Rectangular with launder at or near end	-10

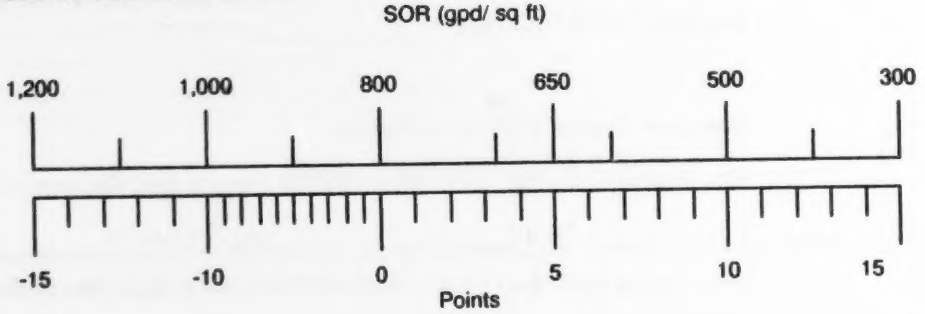
Clarifier Configuration Point Score = ________ ⑤

Calculate Clarifier Surface Overflow Rate (SOR):

$$\text{SOR} = \frac{\text{Peak Month Average Daily Flow}}{\text{Clarifier Surface Area}}$$

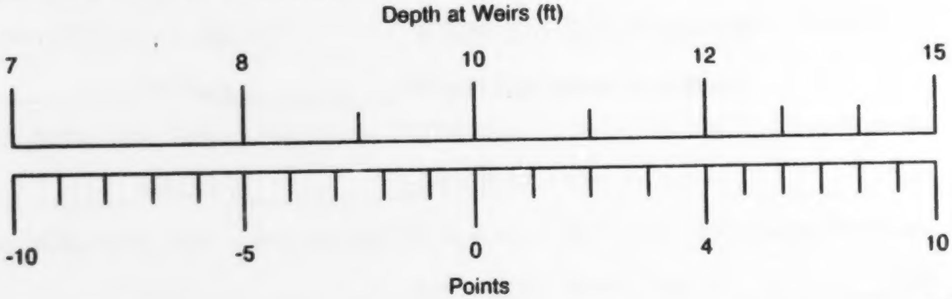
$$\text{SOR} = \frac{(\qquad\qquad\qquad\qquad \text{gpd})}{(\qquad\qquad\qquad\qquad \text{sq ft})} = \underline{\qquad\qquad\qquad} \text{ gpd/sq ft}$$

Determine SOR Point Score:



SOR Point Score = ________ ⑥

Determine Depth at Weirs Point Score:



Depth at Weirs Point Score = ________ ⑦

Determine Return Activated Sludge Point Score:

RAS Removal	Points
Circular, rapid withdrawal	10
Circular, scraper to hopper	8
Rectangular, co-current scraper	2
Rectangular, counter-current scraper	0
No mechanical removal	-5

RAS Removal Point Score = ________ ⑧

Determine Typical RAS Rate from Following:

Process Type	RAS Rate, % of Average Daily Wastewater Flow	
	Minimum	Maximum
Conventional (plug flow or complete mix)	25	100
Extended Aeration (including oxidation ditches)	50	100
Contact Stabilization	50	125

Minimum Typical RAS Rate = ____________ percent

MaximumTypical RAS Rate = ____________ percent

Calculate Typical RAS Flow Range:

Min. Typical RAS Rate x Min. Month POTW Flow = Min. Recommended RAS Flow

(___________%) x (_________________god) x (0.01) = ___________gpd

Max. Typical RAS Rate x Max. Month POTW Flow = Max. Recommended RAS Flow

(___________%) x (_________________god) x (0.01) = ___________gpd

Determine Possible RAS Flow Range for Existing Facilities:

Minimum Possible RAS Flow = ___________gpd

Maximum Possible RAS Flow = ___________gpd

Determine RAS Control Point Score:

RAS Control	Points
The possible RAS flow range is completely within the typical RAS flow range and the capability to measure RAS flow exists	10
The possible RAS flow range is completely within the typical RAS flow range but the capability to measure RAS flow does not exist	7
50% of the typical RAS flow range is covered by the possible RAS flow range and the capability to measure RAS flow exists	5
50% of the typical RAS flow range is covered by the possible RAS flow range but the capability to measure RAS flow does not exist	0
The possible RAS flow range is completely outside the typical RAS flow range	-5

RAS Control Point Score = ________ ⑨

Add Scores 5, 6, 7, 8, and 9 to Obtain Subtotal for Secondary Clarifier:

Secondary Clarifier Subtotal = ________ ⑩

Sludge Handling Capability

Determine Sludge Controllability Point Score:

Controllability	Points
Automated sampling and volume control	5
Metered volume and hand sampling	3
Hand measured volume and hand sampling	2
Sampling or volume measurement by hand not practical	0

Sludge Controllability Point Score = ________ ⑪

Calculate Expected BOD$_5$ Mass to be Removed (in the following calculations, 1.25 is a variability factor, described in Chapter 2):

POTW w/Primary Clarification:

Primary BOD$_{5in}$ - Primary BOD$_{5out}$ = Primary BOD$_5$ Concentration Removed

(__________mg/L) - (__________mg/L) = __________mg/L

Primary BOD$_{5out}$ - POTW Effluent BOD$_5$ = Secondary BOD$_5$ Concentration Removed

(__________mg/L) - (__________mg/L) = __________mg/L

Prim. BOD$_5$ Conc. Rem. x Avg. Annual POTW Flow x 1.25 = Prim. BOD$_5$ Mass Removed

(__________mg/L) x (__________gpd) x (8.34×10^{-6}) x 1.25 = __________lb/d

Sec. BOD$_5$ Conc. Rem. x Avg. Annual POTW Flow x 1.25 = Sec. BOD$_5$ Mass Removed

(__________mg/L) x (__________gpd) x (8.34×10^{-6}) x 1.25 = __________lb/d

POTW w/o Primary Clarification:

BOD_{5in} - POTW Effluent BOD_5 = Total BOD_5 Concentration Removed

(____________mg/L) - (____________mg/L) = ____________mg/L

Total BOD_5 Conc. Rem. x Avg. Annual POTW Flow x 1.25 = Total BOD_5 Mass Removed

(____________mg/L) x (____________gpd) x (8.34×10^{-6}) x 1.25 = ____________lb/d

Determine Typical Unit Sludge Production From Following:

Process Type	lb TSS (sludge)/lb BOD_5 Removed
Primary Clarification	1.7
Activated Sludge w/Primary Clarification	0.7
Activated Sludge w/o Primary Clarification	
Conventional[1]	0.85
Extended Aeration[2]	0.65
Contact Stabilization	1.0

[1] Includes tapered aeration, step feed, plug flow, and complete mix with wastewater times < 10 hr.

[2] Includes oxidation ditch.

If plant records include actual sludge production data, the actual unit sludge production value should be compared to the typical value. If a discrepancy of more than 15 percent exists between the two values, further evaluation is needed. If not, use the actual unit sludge production value.

Calculate Expected Sludge Mass:

POTW w/Primary Clarification:

Unit Sludge Production x Primary BOD_5 Mass Removed = Primary Sludge Mass

(____________lb/lb) - (____________lb/d) = ____________lb/d

Unit Sludge Production x Secondary BOD_5 Mass Removed = Secondary Sludge Mass

(____________lb/lb) - (____________lb/d) = ____________lb/d

Total Sludge Mass = ____________lb/d

POTW w/o Primary Clarification:

Unit Sludge Production x Total BOD_5 Mass Removed = Total Sludge Mass

(____________lb/lb) - (____________lb/d) = ____________lb/d

Determine Typical Unit Sludge Production From Following:

Sludge Type	Waste Concentration, mg/l
Primary	50,000
Activated	
Return Sludge/Conventional	6,000
Return Sludge/Extended Aeration	7,500
Return Sludge/Contact Stabilization	8,000
Return Sludge/small plant with low SOR[1]	10,000
Separate waste hopper in secondary clarifier	12,000

[1] Returns can often be shut off for short periods to thicken waste sludge in clarifiers with surface overflow rates < 500 gpd/sq ft.

Calculate Expected Sludge Volume:

POTW w/Primary Clarification:

$$\text{Sludge Volume} = \frac{\text{Primary Sludge Mass}}{\text{Primary Sludge Concentration}}$$

$$\text{Sludge Volume} = \frac{(\qquad\qquad\qquad \text{lb/d})}{(\qquad 50{,}000 \qquad \text{mg/l})} \times (120{,}000) = \underline{\qquad\qquad\qquad} \text{ gpd}$$

$$\text{Sludge Volume} = \frac{\text{Secondary Sludge Mass}}{\text{Secondary Sludge Concentration}}$$

$$\text{Sludge Volume} = \frac{(\qquad\qquad\qquad \text{lb/d})}{(\qquad\qquad\qquad \text{mg/l})} \times (120{,}000) = \underline{\qquad\qquad\qquad} \text{ gpd}$$

$$\text{Total Sludge Volume} = \underline{\qquad\qquad\qquad} \text{ gpd}$$

POTW w/o Primary Clarification:

$$\text{Total Sludge Volume} = \frac{\text{Total Sludge Mass}}{\text{Waste Sludge Concentration}}$$

$$\text{Total Sludge Volume} = \frac{(\qquad\qquad\qquad \text{lb/d})}{(\qquad\qquad\qquad \text{mg/l})} \times (120{,}000) = \underline{\qquad\qquad\qquad} \text{ gpd}$$

Calculate Capability of Sludge Handling Unit Processes:

1. Establish capability of *each* existing sludge handling process (treatment and disposal). The most common unit processes for which this calculation will have to be performed are:

   - Aerobic digestion
   - Anaerobic digestion
   - Gravity thickening
   - Mechanical dewatering
   - Drying beds
   - Liquid haul

For example, the capability of a gravity thickener is based on the maximum sludge loading it must handle:

$$\text{Thickener Loading} = \frac{\text{Total Sludge Mass}}{\text{Thickener Surface Area}}$$

$$\text{Thickener Loading} = \frac{(\qquad\qquad\text{lb/d})}{(\qquad\qquad\text{sq ft})} = \underline{\qquad\qquad} \text{ lb/d/sq ft}$$

2. Determine percentage of the expected sludge production that each process can handle.

Assume the sludge being thickened by the gravity thickener above is mixed primary and activated. From Table 2-9, 10 lb/d/sq ft is considered typical loading for the thickener. Its capability would therefore be calculated as:

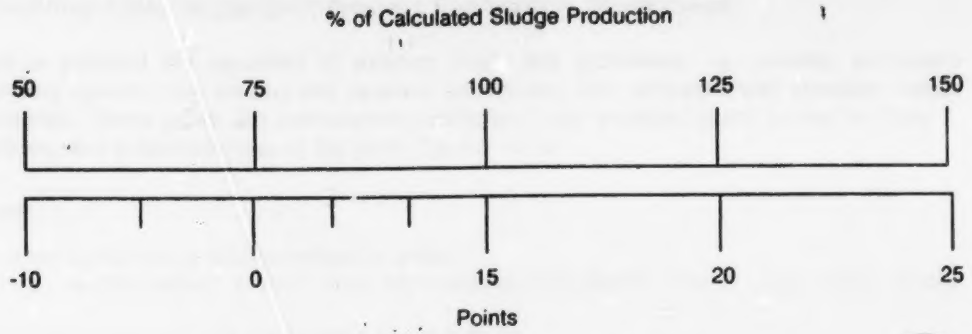
$$\frac{(\qquad 10 \quad \text{lb/d/sq ft})}{(\quad \text{Actual Loading} \quad \text{lb/d/sq ft}} \times 100 = \underline{\qquad\qquad} \text{ percent}$$

List Each Process and Its Associated Sludge Handling Capability and Identify the Lowest Percentage Capability:

Process	Percentage

Lowest Capability = ____________

Determine Sludge Handling Capability Point Score:


% of Calculated Sludge Production
50
75
100
125
150
-10
0
15
20
25
Points

Sludge Handling Capability Point Score = ⑫

Add Scores 11 and 12 to Obtain Subtotal for Sludge Handling Capability:

Sludge Handling Capability Subtotal = ________ ⑬

Compare Subtotals and Total Score with Following to Determine Whether POTW is Type 1, Type 2, or Type 3:

		Points Required		
	Score	Type 1	Type 2	Type 3
Aeration Basin	________ (4)	13-30	0-12	<0
Secondary Clarifier	________ (10)	25-55	0-24	<0
Sludge Handling Capability	________ (13)	10-30	0-9	<0
Total	________	60-115	20-59	<20

	Type
Aeration Basin	________
Secondary Clarifier	________
Sludge Handling Capability	________
Total	________

Select the Worst Case: POTW is Type ________

Appendix M

Trickling Filter Major Unit Process Evaluation Worksheet

This worksheet is used to evaluate the capability of existing major unit processes, i.e., aerator, secondary clarifier, and sludge handling system. Key loading and process parameters are compared with standard values and point scores are assigned. These points are subsequently compared with expected point scores for Type 1, Type 2, and Type 3 facilities, and a determination of the plant Type is made.

Instructions for use:

- Proceed through the steps contained in this worksheet *in order.*
- Use actual values in lieu of calculations if such data are available and appear reliable, e.g., waste sludge volume.
- When assigning points, interpolate and use the nearest whole number.
- Minimum and maximum point values are indicated - do not exceed the range illustrated.

"Aerator" **Calculate Equivalent Filter Media Volume:**

$$\text{Equivalent Filter Media Volume} = \frac{\text{Actual Filter Media Specific Surface Area}}{\text{Rock Filter Media Specific Surface Area}} \times \text{Actual Media Volume}$$

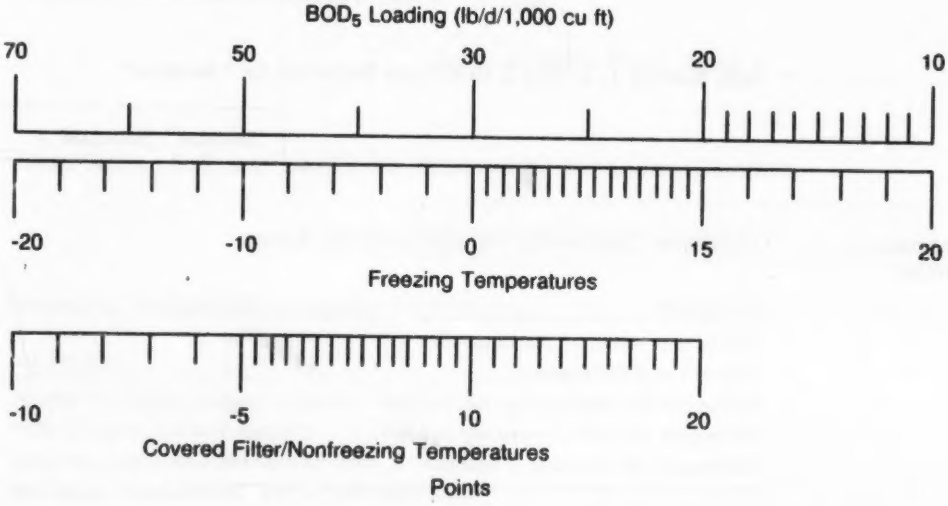
$$\text{Equivalent Filter Media Volume} = \frac{(\qquad\qquad \text{sq ft/cu ft})}{(\quad 13 \quad \text{sq ft/cu ft})} \times (\underline{\qquad\qquad}\ \text{cu ft}) = \underline{\qquad\qquad}\ \text{cu ft}$$

Calculate BOD_5 Loading:

$$BOD_5\ \text{Loading} = \frac{\text{Primary Effluent } BOD_5}{\text{Equivalent Filter Media Volume}}$$

$$BOD_5\ \text{Loading} = \frac{(\qquad\qquad \text{lb/d})}{(\qquad\qquad \text{cu ft})} \times 1{,}000 = \underline{\qquad\quad}\ \text{lb } BOD_5\text{/d/1,000 cu ft}$$

Determine BOD_5 Loading Point Score:



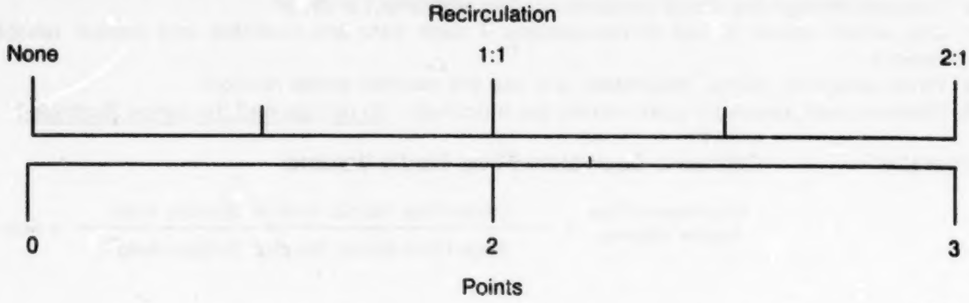
BOD_5 Loading Point Score = ________ ①

Calculate Recirculation Ratio:

$$\text{Recirculation Ratio} = \frac{\text{Return Flow}}{\text{Peak Month Avg. Daily Wastewater Flow}}$$

$$\text{Recirculation Ratio} = \frac{(\qquad \text{gpd})}{(\qquad ,\ \text{gpd})} = \underline{\qquad} : 1$$

Determine Recirculation Ratio Point Score:



Recirculation Ratio Point Score = ________ ②

Determine Anaerobic Side Streams Point Score:

Anaerobic Side Streams[1]	Points
Not returned to plant	0
Returned to the wastewater stream ahead of TF	
returned to flow equalization tank or prim. clar.	-6
returned directly ahead of trickling filter	-10

[1] Supernatant from anaerobic digesters or filtrate/concentrate from the dewatering processes following anaerobic digesters.

Anaerobic Side Streams Point Score = ________ ③

Add Scores 1, 2, and 3 to Obtain Subtotal for "Aerator":

"Aerator" Subtotal = ________ ④

Secondary Clarifier

Determine Clarifier Configuration Point Score:

Configuration	Points
Circular with "donut" or interior launders	10
Circular with weirs on walls	5
Rectangular with 33% covered with launders	5
Rectangular with 20% covered with launders	0
Rectangular with launder at or near end	-10

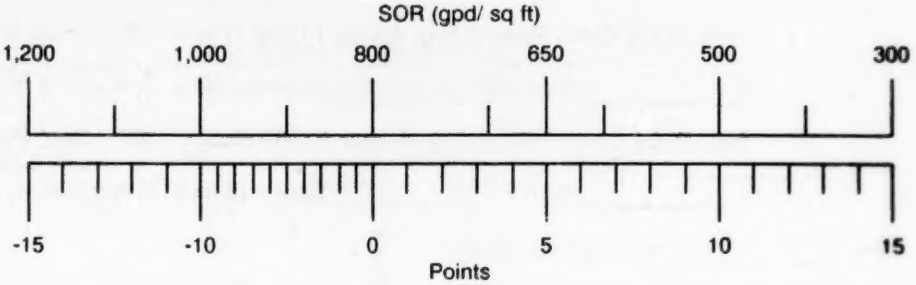
Clarifier Configuration Point Score = ________ ⑤

Calculate Clarifier Surface Overflow Rate (SOR):

$$\text{SOR} = \frac{\text{Peak Month Average Daily Flow}}{\text{Clarifier Surface Area}}$$

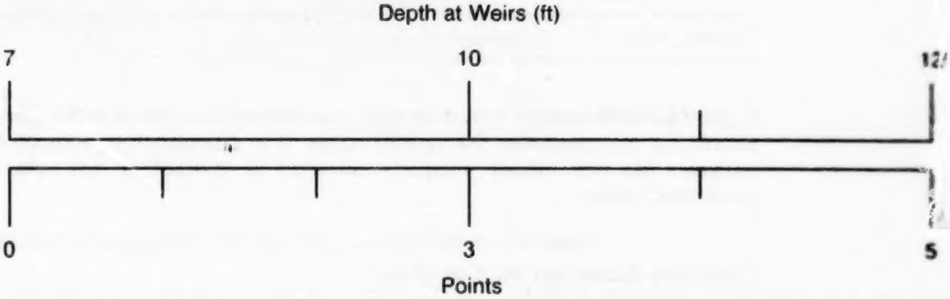
$$\text{SOR} = \frac{(\qquad\qquad \text{gpd})}{(\qquad\qquad \text{sq ft})} = \underline{\qquad\qquad} \text{ gpd/sq ft}$$

Determine SOR Point Score:


SOR (gpd/ sq ft)
1,200
1,000
800
650
500
300
-15
-10
0
5
10
15
Points

SOR Point Score = ________ ⑥

Determine Depth at Weirs Point Score:


Depth at Weirs (ft)
7
10
12
0
3
5
Points

Depth at Weirs Point Score = ________ ⑦

Add Scores 5, 6, and 7 to Obtain Subtotal for Secondary Clarifier:

Secondary Clarifier Subtotal = ________ ⑧

Sludge Handling Capability

Determine Sludge Controllability Point Score:

Controllability	Points
Automated sampling and volume control	5
Metered volume and hand sampling	3
Hand measured volume and hand sampling	2
Sampling or volume measurement by hand not practical	0

Sludge Controllability Point Score = ________ ⑨

Calculate Expected BOD$_5$ Mass to be Removed (in the following calculations, 1.25 is a variability factor described in Chapter 2):

Primary BOD$_{5in}$ - Primary BOD$_{5out}$ = Primary BOD$_5$ Concentration Removed

(__________mg/l) - (__________mg/l) = __________mg/l

Primary BOD$_{5out}$ - POTW Effluent BOD$_5$ = Secondary BOD$_5$ Concentration Removed

(__________mg/l) - (__________mg/l) = __________mg/l

Prim. BOD$_5$ Conc. Rem. x Avg. Annual POTW Flow x 1.25 = Prim. BOD$_5$ Mass Removed

(__________mg/l) x (__________gpd) x (8.34 x 10^{-6}) x 1.25 = __________lb/d

Sec. BOD$_5$ Conc. Rem. x Avg. Annual POTW Flow x 1.25 = Sec. BOD$_5$ Mass Removed

(__________mg/l) x (__________gpd) x (8.34 x 10^{-6}) x 1.25 = __________lb/d

Determine Typical Unit Sludge Production From Following:

Process Type	lb TSS (sludge)/lb BOD$_5$ Removed
Primary Clarification	1.7
Trickling Filter	0.9

If plant records include actual sludge production data, the actual unit sludge production value should be compared to the typical value. If a discrepancy of more than 15 percent exists between the two values, further evaluation is needed. If not, use the actual unit sludge production value.

Calculate Expected Sludge Mass:

Unit Sludge Production x Primary BOD$_5$ Mass Removed = Primary Sludge Mass

(__________lb/lb) - (__________lb/d) = __________lb/d

Unit Sludge Production x Secondary BOD$_5$ Mass Removed = Secondary Sludge Mass

(__________lb/lb) - (__________lb/d) = __________lb/d

Total Sludge Mass = __________lb/d

Calculate Expected Sludge Volume:

Method 1 (Primary and Secondary Sludge Wasted Separately):

$$\text{Sludge Volume} = \frac{\text{Primary Sludge Mass}}{\text{Primary Sludge Concentration}}$$

$$\text{Sludge Volume} = \frac{(\qquad\qquad\qquad \text{lb/d})}{(\qquad 50{,}000 \qquad \text{mg/l})} \times (120{,}000) = \underline{\qquad\qquad} \text{ gpd}$$

$$\text{Sludge Volume} = \frac{\text{Secondary Sludge Mass}}{\text{Secondary Sludge Concentration}}$$

$$\text{Sludge Volume} = \frac{(\qquad\qquad\qquad \text{lb/d})}{(\qquad 20{,}000 \qquad \text{mg/l})} \times (120{,}000) = \underline{\qquad\qquad} \text{ gpd}$$

$$\text{Total Sludge Volume} = \underline{\qquad\qquad} \text{ gpd}$$

Method 2 (Secondary Sludge Wasted to Primary):

$$\text{Total Sludge Volume} = \frac{\text{Total Sludge Mass}}{\text{Combined Sludge Concentration}}$$

$$\text{Total Sludge Volume} = \frac{(\qquad\qquad\qquad \text{lb/d})}{(\qquad 35{,}000 \qquad \text{mg/l})} \times (120{,}000) = \underline{\qquad\qquad} \text{ gpd}$$

Calculate Capability Sludge Handling Unit Processes:

1. Establish capability of *each* existing sludge handling process (treatment and disposal). The most common unit processes for which this calculation will have to be performed are:

   - Aerobic digestion
   - Anaerobic digestion
   - Gravity thickening
   - Mechanical dewatering
   - Drying beds
   - Liquid haul

For example, the capability of a gravity thickener is based on the maximum sludge loading it must handle:

$$\text{Thickener Loading} = \frac{\text{Total Sludge Mass}}{\text{Thickener Surface Area}}$$

$$\text{Thickener Loading} = \frac{(\qquad\qquad\qquad \text{lb/d})}{(\qquad\qquad\qquad \text{sq ft})} = \underline{\qquad\qquad} \text{ lb/d/sq ft}$$

2. **Determine percentage of the expected sludge production that each process can handle.**

Assume the sludge being thickened by the gravity thickener above is from a trickling filter. From Table 2-9, 8 lb/d/sq ft is considered typical loading for the thickener. Its capability would therefore be calculated as:

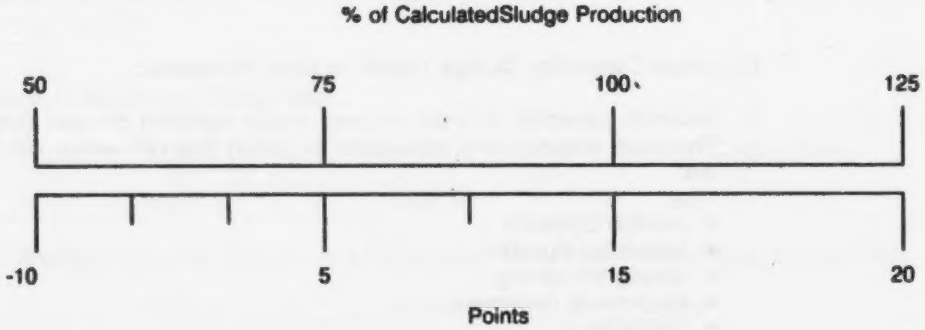
$$\frac{(\quad 8 \quad \text{lb/d/sq ft})}{(\quad \text{Actual Loading} \quad \text{lb/d/sq ft})} \times 100 = \underline{\hspace{3cm}} \text{ percent}$$

List Each Process and Its Associated Sludge Handling Capability and Identify the Lowest Percentage Capability:

Process	Percentage

Lowest Percent Capability = ____________

Determine Sludge Handling Capability Point Score:



Sludge Handling Capability Point Score = ________ ⑩

Add Scores 9 and 10 to Obtain Subtotal for Sludge Handling Capability :

Sludge Handling Capability Subtotal = ________ ⑪

Compare Subtotals and Total Score With Following to Determine Whether POTW Is Type 1, Type 2, or Type 3:

		Points Required		
	Score	Type 1	Type 2	Type 3
"Aerator"	________ (4)	17-23	0-16	<0
Secondary Clarifier	________ (8)	17-30	0-16	<0
Sludge Handling Capability	________ (11)	10-30	0-9	<0
Total	________	45-83	15-44	<15

	Type
"Aerator"	________
Secondary Clarifier	________
Sludge Handling Capability	________
Total	________

Select the Worst Case: POTW is Type ________

Appendix N

RBC Major Unit Process Evaluation Worksheet

This worksheet is used to evaluate the capability of existing major unit processes, i.e., aerator, secondary clarifier, and sludge handling system. Key loading and process parameters are compared with standard values and point scores are assigned. These points are subsequently compared with expected point scores for Type 1, 2, and 3 facilities, and a determination of the plant Type is made.

Instructions for use:

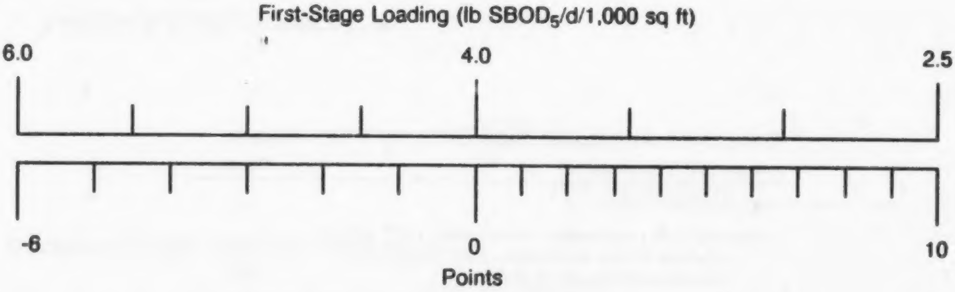
- Proceed through the steps contained in this worksheet *in order*.
- Use actual values in lieu of calculations if such data are available and appear reliable, e.g., waste sludge volume.
- When assigning points, interpolate and use the nearest whole number.
- Minimum and maximum point values are indicated - do not exceed the range illustrated.

"Aerator" **Calculate First-Stage Loading:**

$$\text{BOD}_5\ \text{Loading} = \frac{\text{Avg. Daily RBC SBOD}_5\ \text{Load}}{\text{First-Stage Media Surface Area}} \quad \text{or} \quad \frac{0.5\ \text{Avg. Daily RBC BOD}_5\ \text{Load}}{\text{First-Stage Media Surface Area}}$$

$$\text{BOD}_5\ \text{Loading} = \frac{(\qquad\qquad \text{lb/d})}{(\qquad\qquad \text{sq ft})} \times 1{,}000 = \underline{\qquad}\ \text{lb SBOD}_5\text{/d/1,000 sq ft}$$

Determine First-Stage Loading Point Score:



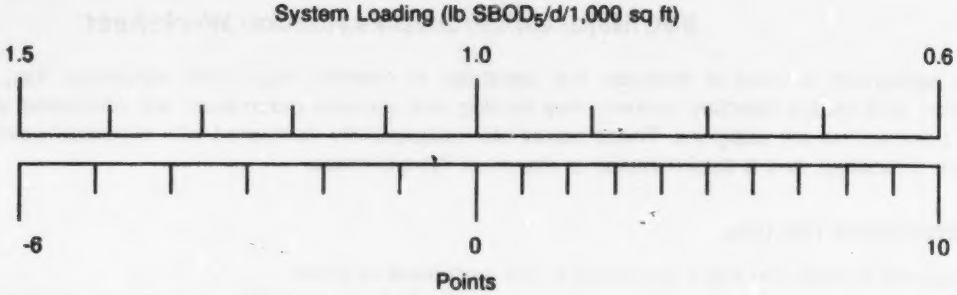
First-Stage Loading Point Score = ________ ①

Calculate System Loading:

$$\text{BOD}_5\ \text{Loading} = \frac{\text{Avg. Daily RBC SBOD}_5\ \text{Load}}{\text{Total Media Surface Area}} \quad \text{or} \quad \frac{0.5\ \text{Avg. Daily RBC BOD}_5\ \text{Load}}{\text{Total Media Surface Area}}$$

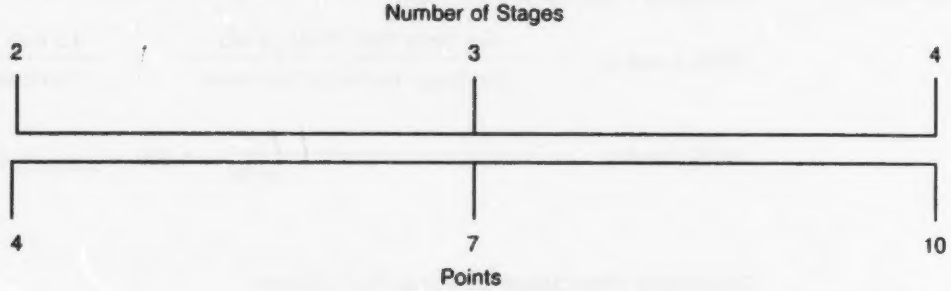
$$\text{BOD}_5\ \text{Loading} = \frac{(\qquad\qquad \text{lb/d})}{(\qquad\qquad \text{sq ft})} \times 1{,}000 = \underline{\qquad}\ \text{lb SBOD}_5\text{/d/1,000 sq ft}$$

Determine System Loading Point Score:


System Loading (lb SBOD$_5$/d/1,000 sq ft)
1.5
1.0
0.6
-6
0
10
Points

System Loading Point Score = ________ ②

Determine Number of Stages Point Score:


Number of Stages
2
3
4
4
7
10
Points

Recirculation Ratio Point Score = ________ ③

Determine Anaerobic Side Streams Point Score:

Anaerobic Side Streams[1]	Points
Not returned to plant	0
Returned to the wastewater stream ahead of the RBC	
returned to flow equalization tank or prim. clar.	-6
returned directly ahead of RBC	-10

[1] Supernatant from anaerobic digesters or filtrate/concentrate from the dewatering processes following anaerobic digesters.

Anaerobic Side Streams Point Score = ________ ④

Add Scores 1, 2, 3 and 4 to Obtain Subtotal for "Aerator":

"Aerator" Subtotal = ________ ⑤

Secondary Clarifier

Determine Clarifier Configuration Point Score:

Configuration	Points
Circular with "donut" or interior launders	10
Circular with weirs on walls	5
Rectangular with 33% covered with launders	5
Rectangular with 20% covered with launders	0
Rectangular with launder at or near end	-10

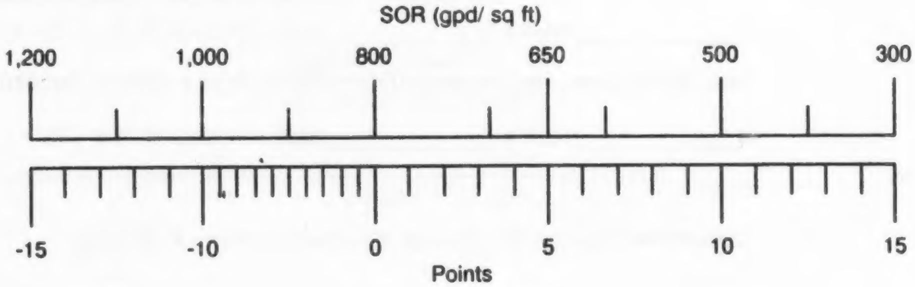
Clarifier Configuration Point Score = ________ ⑥

Calculate Clarifier Surface Overflow Rate (SOR):

$$\text{SOR} = \frac{\text{Peak Month Average Daily Flow}}{\text{Clarifier Surface Area}}$$

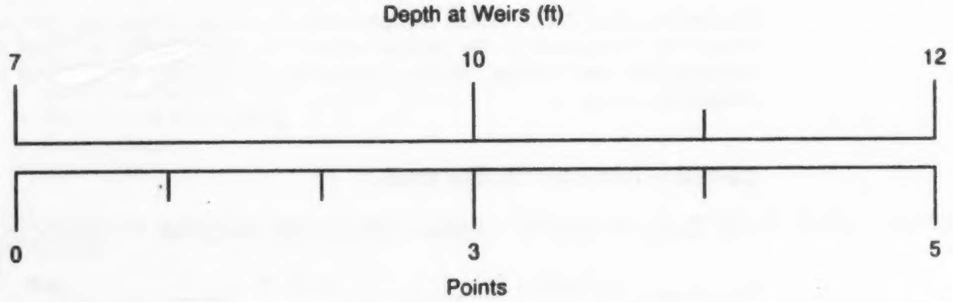
$$\text{SOR} = \frac{(\qquad\qquad \text{gpd})}{(\qquad\qquad \text{sq ft})} = \underline{\qquad\qquad} \text{ gpd/sq ft}$$

Determine SOR Point Score:


SOR (gpd/ sq ft)
1,200
1,000
800
650
500
300
-15
-10
0
5
10
15
Points

SOR Point Score = ________ ⑦

Determine Depth at Weirs Point Score:


Depth at Weirs (ft)
7
10
12
0
3
5
Points

Depth at Weirs Point Score = ________ ⑧

Add Scores 5, 6, and 7 to Obtain Subtotal for Secondary Clarifier:

Secondary Clarifier Subtotal = ________ ⑨

Sludge Handling Capability

Determine Sludge Controllability Point Score:

Controllability	Points
Automated sampling and volume control	5
Metered volume and hand sampling	3
Hand measured volume and hand sampling	2
Sampling or volume measurement by hand not practical	0

Sludge Controllability Point Score = ________ ⑩

Calculate Expected BOD$_5$ Mass to be Removed (in the following calculations, 1.25 is a variability factor discussed in Chapter 2):

Primary BOD$_{5in}$ - Primary BOD$_{5out}$ = Primary BOD$_5$ Concentration Removed

(__________mg/l) - (__________mg/l) = __________mg/l

Primary BOD$_{5out}$ - POTW Effluent BOD$_5$ = Secondary BOD$_5$ Concentration Removed

(__________mg/l) - (__________mg/l) = __________mg/l

Prim. BOD$_5$ Conc. Rem. x Avg. Annual POTW Flow x 1.25 = Prim. BOD$_5$ Mass Removed

(__________mg/l) x (__________gpd) x (8.34×10^{-6}) x 1.25 = __________lb/d

Sec. BOD$_5$ Conc. Rem. x Avg. Annual POTW Flow x 1.25 = Sec. BOD$_5$ Mass Removed

(__________mg/l) x (__________gpd) x (8.34×10^{-6}) x 1.25 = __________lb/d

Determine Typical Unit Sludge Production From Following:

Process Type	lb TSS (sludge)/lb BOD$_5$ Removed
Primary Clarification	1.7
RBC	1.0

If plant records include actual sludge production data, the actual unit sludge production value should be compared to the typical value. If a discrepancy of more than 15 percent exists between the two values, further evaluation is needed. If not, use the actual unit sludge production value.

Calculate Expected Sludge Mass:

Unit Sludge Production x Primary BOD$_5$ Mass Removed = Primary Sludge Mass

(__________lb/lb) x (__________lb/d) = __________lb/d

Unit Sludge Production x Secondary BOD$_5$ Mass Removed = Secondary Sludge Mass

(__________lb/lb) x (__________lb/d) = __________lb/d

Total Sludge Mass = __________lb/d

Calculate Expected Sludge Volume:

Method 1 (Primary and Secondary Sludge Wasted Separately):

$$\text{Sludge Volume} = \frac{\text{Primary Sludge Mass}}{\text{Primary Sludge Concentration}}$$

$$\text{Sludge Volume} = \frac{(\qquad\qquad \text{lb/d})}{(\qquad 50{,}000 \qquad \text{mg/l})} \times (120{,}000) = \underline{\qquad\qquad\qquad} \text{ gpd}$$

$$\text{Sludge Volume} = \frac{\text{Secondary Sludge Mass}}{\text{Secondary Sludge Concentration}}$$

$$\text{Sludge Volume} = \frac{(\qquad\qquad \text{lb/d})}{(\qquad 20{,}000 \qquad \text{mg/l})} \times (120{,}000) = \underline{\qquad\qquad\qquad} \text{ gpd}$$

$$\text{Total Sludge Volume} = \underline{\qquad\qquad\qquad} \text{ gpd}$$

Method 2 (Secondary Sludge Wasted to Primary):

$$\text{Total Sludge Volume} = \frac{\text{Total Sludge Mass}}{\text{Combined Sludge Concentration}}$$

$$\text{Total Sludge Volume} = \frac{(\qquad\qquad \text{lb/d})}{(\qquad 35{,}000 \qquad \text{mg/l})} \times (120{,}000) = \underline{\qquad\qquad\qquad} \text{ gpd}$$

Calculate Capability Sludge Handling Unit Processes:

1. Establish capability of *each* existing sludge handling process (treatment and disposal). The most common unit processes for which this calculation will have to be performed are:

   - Aerobic digestion
   - Anaerobic digestion
   - Gravity thickening
   - Mechanical dewatering
   - Drying beds
   - Liquid haul

   For example, the capability of a gravity thickener is based on the maximum sludge loading it must handle:

$$\text{Thickener Loading} = \frac{\text{Total Sludge Mass}}{\text{Thickener Surface Area}}$$

$$\text{Thickener Loading} = \frac{(\qquad\qquad \text{lb/d})}{(\qquad\qquad \text{sq ft})} = \underline{\qquad\qquad\qquad} \text{ lb/d/sq ft}$$

2. **Determine percentage of the expected sludge production that each process can handle.**

Assume the sludge being thickened by the gravity thickener above is mixed primary and RBC. From Table 2-9, 15 lb/d/sq ft is considered typical loading for the thickener. Its capacity would therefore be calculated as:

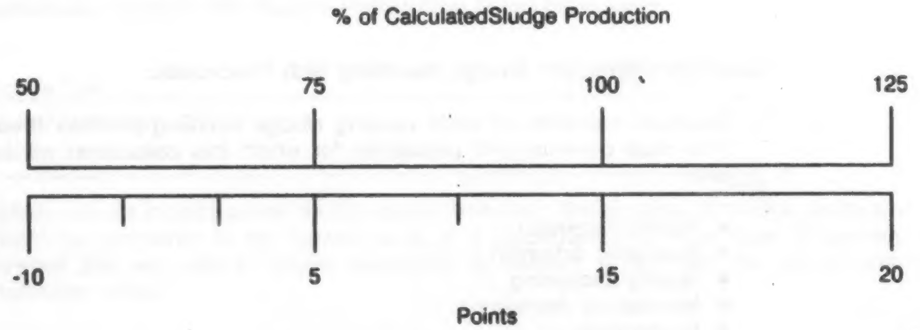
$$\frac{(\quad 15 \quad \text{lb/d/sq ft})}{(\quad \text{Actual Loading} \quad \text{lb/d/sq ft})} \times 100 = \underline{\hspace{3cm}} \text{ percent}$$

List Each Process and Its Associated Sludge Handling Capability and Identify the Lowest Percentage Capability:

Process	Percentage
____________________	____________________
____________________	____________________
____________________	____________________
____________________	____________________
____________________	____________________
____________________	____________________
____________________	____________________

Lowest Capability = ____________________

Determine Sludge Handling Capability Point Score:



Sludge Handling Capability Point Score = ________ ⑪

Add Scores 10 and 11 to Obtain Subtotal for Sludge Handling Capability:

Sludge Handling Capability Subtotal = ________ ⑫

Compare Subtotals and Total Score With Following to Determine Whether POTW is Type 1, 2, or 3:

			Points Required		
	Score		Type 1	Type 2	Type 3
"Aerator"	________	(5)	14-30	0-13	<0
Secondary Clarifier	________	(9)	17-30	0-16	<0
Sludge Handling Capability	________	(12)	10-30	0-9	<0
Total	________		48-90	15-47	<15

	Type
"Aerator"	________
Secondary Clarifier	________
Sludge Handling Capability	________
Total	________

Select the Worst Case: POTW is Type ________

Appendix O

ABF Major Unit Process Evaluation Worksheet

This worksheet is used to evaluate the capability of existing major unit processes, i.e., aerator, secondary clarifier, and sludge handling system. Key loading and process parameters are compared with standard values and point scores are assigned. These points are subsequently compared with expected point scores for Type 1, 2, and 3 facilities and a determination of the plant Type is made.

Instructions for use:

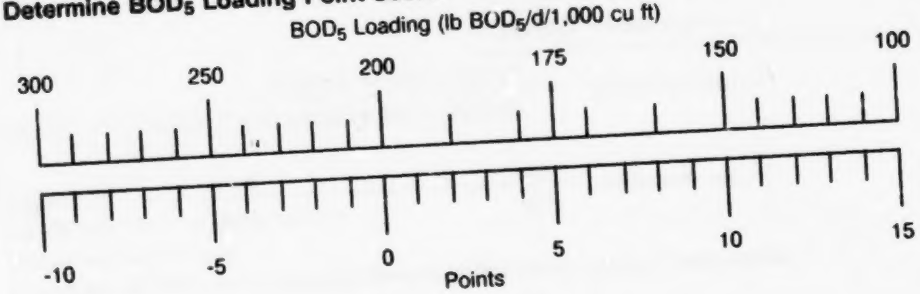
- Proceed through the steps contained in this worksheet *in order*.
- Use actual values in lieu of calculations if such data are available and appear reasonable, e.g., waste sludge volume.
- When assigning points, interpolate and use the nearest whole number.
- Minimum and maximum point values are indicated - do not exceed the range illustrated.

"Aerator" **Calculate BOD$_5$ Loading:**

$$\text{BOD}_5\text{ Loading} = \frac{\text{Avg. Daily Biocell BOD}_5\text{ Loading}}{\text{Biocell Media Volume}}$$

$$\text{BOD}_5\text{ Loading} = \frac{(\qquad\qquad\qquad \text{lb/d})}{(\qquad\qquad\qquad \text{cu ft})} \times 1000 = \underline{\qquad\quad} \text{ lb BOD}_5\text{/d/1000 cu ft}$$

Determine BOD$_5$ Loading Point Score:



BOD$_5$ Loading Point Score **=** ________ ①

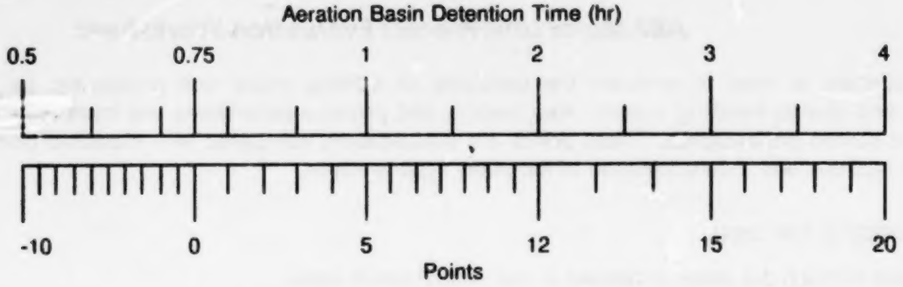
Calculate Aeration Basin Detention Time:

$$\text{Aeration Basin Detention Time} = \frac{\text{Aeration Basin Volume}}{\text{Peak Month Average Daily Flow}}$$

$$\text{Aeration Basin Detention Time} = \frac{(\qquad\qquad\qquad \text{cu ft})}{(\qquad\qquad\qquad \text{gpd})} \times 180 = \underline{\qquad\qquad\qquad} \text{ hr}$$

best copy available

Determine Aeration Basin Detention Time Point Score:



Aeration Basin Detention Time Point Score = ________ ②

Calculate Oxygen Availability:

Mechanical Aeration Systems

If data are not available on oxygen transfer capacity, calculate it as Wire Horsepower (Appendix F) times Actual Oxygen Transfer Rate (Appendix E).

(__________hp) x (__________lb/hp-hr) x 24 = __________lb O_2/d

Diffused Air Aeration Systems

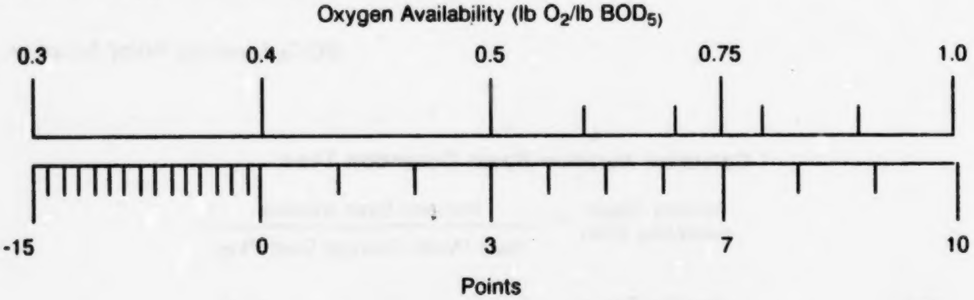
If data are not available on oxygen transfer capacity, calculate an actual oxygenation rate (Section 2.3.3.1).

__________lb O_2/d

$$\text{Oxygen Availability} = \frac{\text{Oxygen Transfer Capacity}}{\text{BOD}_5\text{ Loading to Aerator}}$$

$$\text{Oxygen Availability} = \frac{(\qquad\qquad \text{lb/d})}{(\qquad\qquad \text{lb/d})} = \_\_\_\_\_\_ \text{ lb } O_2/\text{lb BOD}_5$$

Determine Oxygen Availability Point Score:



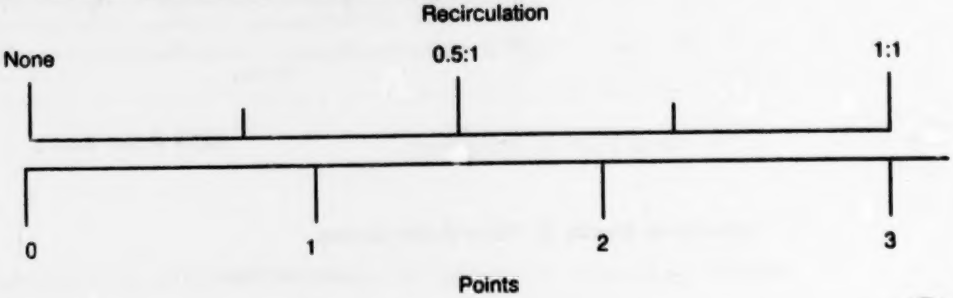
Oxygen Availability Point Score = ________ ③

Calculate Recirculation Ratio:

$$\text{Recirculation Ratio} = \frac{\text{Return Flow}}{\text{Peak Month Average Daily Wastewater Flow}}$$

$$\text{Recirculation Ratio} = \frac{(\qquad\qquad \text{gpd})}{(\qquad\qquad \text{gpd})} = \_\_\_\_\_\_\_ : 1$$

Determine Recirculation Ratio Point Score:



***Recirculation Ratio Point Score* = ________ ④**

Add Scores 1, 2, 3 and 4 to Obtain Subtotal for "Aerator":

***"Aerator" Subtotal* = ________ ⑤**

Secondary Clarifier

Determine Clarifier Configuration Point Score:

Configuration	Points
Circular with "donut" or interior launders	10
Circular with weirs on walls	5
Rectangular with 33% covered with launders	5
Rectangular with 20% covered with launders	0
Rectangular with launder at or near end	-10

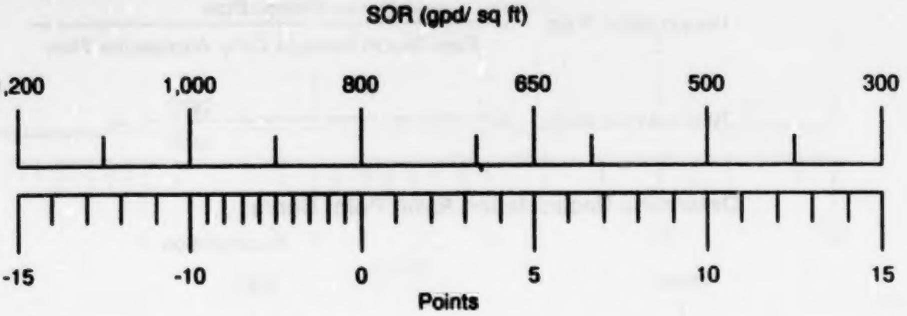
***Clarifier Configuration Point Score* = ________ ⑥**

Calculate Clarifier Surface Overflow Rate (SOR):

$$\text{SOR} = \frac{\text{Peak Month Average Daily Flow}}{\text{Clarifier Surface Area}}$$

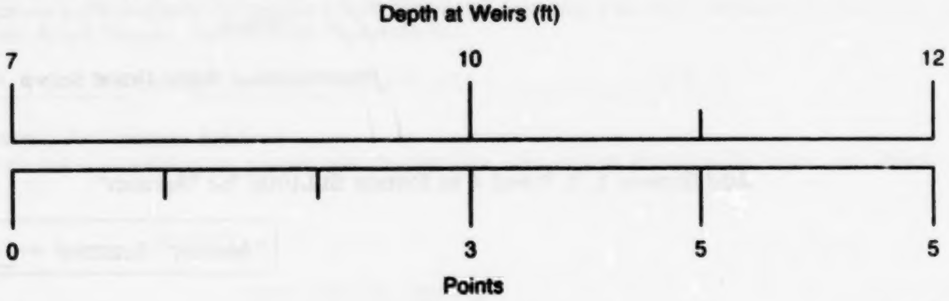
$$\text{SOR} = \frac{(\qquad\qquad \text{gpd})}{(\qquad\qquad \text{sq ft})} = \_\_\_\_\_\_\_\_\_\_ \text{ gpd/sq ft}$$

Determine SOR Point Score:


SOR (gpd/ sq ft)
1,200
1,000
800
650
500
300
-15
-10
0
5
10
15
Points

***SOR Point Score* = ________** ⑦

Determine Depth at Weirs Point Score:


Depth at Weirs (ft)
7
10
12
0
3
5
5
Points

***Depth at Weirs Point Score* = ________** ⑧

Calculate Desired RAS Flow Range:

Min. Typical RAS Rate x Min. Month POTW Flow = Min. Recommended RAS Flow

(25%) x (________________gpd) x (0.01) = ____________gpd

Max. Typical RAS Rate x Max. Month POTW Flow = Max. Recommended RAS Flow

(100%) x (________________gpd) x (0.01) = ____________gpd

Determine Possible RAS Flow Range:

Minimum Possible RAS Flow = ____________gpd

Maximum Possible RAS Flow = ____________gpd

Determine RAS Control Point Score:

RAS Control	Points
The possible RAS flow range is completely within the typical RAS flow range and the capability to measure RAS flow exists	10
The possible RAS flow range is completely within the typical RAS flow range but the capability to measure RAS flow does not exist	7
50% of the typical RAS flow range is covered by the possible RAS flow range and the capability to measure RAS flow exists	5
50% of the typical RAS flow range is covered by the possible RAS flow range but the capability to measure RAS flow does not exist	0
The possible RAS flow range is completely outside the typical RAS flow range	-5

RAS Control Point Score = ________ ⑨

Add Scores 5, 6, 7, 8, and 9 to Obtain Subtotal for Secondary Clarifier:

Secondary Clarifier Subtotal = ________ ⑩

Sludge Handling Capability

Determine Sludge Controllability Point Score:

Controllability	Points
Automated sampling and volume control	5
Metered volume and hand sampling	3
Hand measured volume and hand sampling	2
Sampling or volume measurement by hand not practical	0

Sludge Controllability Point Score = ________ ⑪

Calculate Expected BOD_5 Mass to be Removed (in the following calculations, 1.25 is a variability factor discussed in Chapter 2):

Primary BOD_{5in} - Primary BOD_{5out} = Primary BOD_5 Concentration Removed

(__________mg/l) - (__________mg/l) = __________mg/l

Primary BOD_{5out} - POTW Effluent BOD_5 = Secondary BOD_5 Concentration Removed

(__________mg/l) - (__________mg/l) = __________mg/l

Prim. BOD_5 Conc. Rem. x Avg. Annual POTW Flow x 1.25 = Prim. BOD_5 Mass Removed

(__________mg/l) x (__________gpd) x (8.34×10^{-6}) x 1.25 = __________lb/d

Sec. BOD_5 Conc. Rem. x Avg. Annual POTW Flow x 1.25 = Sec. BOD_5 Mass Removed

(__________mg/l) x (__________gpd) x (8.34×10^{-6}) x 1.25 = __________lb/d

Determine Typical Unit Sludge Production From Following:

Process Type	lb TSS (sludge)/lb BOD_5 Removed
ABF	1.0

If plant records include actual sludge production data, the actual unit sludge production value should be compared to the typical value. If a discrepancy of more than 15 percent exists between the two values, further evaluation is needed. If not, use the actual unit sludge production value.

Calculate Expected Sludge Mass:

Unit Sludge Production x Primary BOD_5 Mass Removed = Primary Sludge Mass

(____________lb/lb) · (____________lb/d) = ____________lb/d

Unit Sludge Production x Secondary BOD_5 Mass Removed = Secondary Sludge Mass

(____________lb/lb) · (____________lb/d) = ____________lb/d

Total Sludge Mass = ____________lb/d

Calculate Expected Sludge Volume:

Method 1 (Primary and Secondary Sludge Wasted Separately):

$$\text{Sludge Volume} = \frac{\text{Primary Sludge Mass}}{\text{Primary Sludge Concentration}}$$

$$\text{Sludge Volume} = \frac{(\qquad\qquad \text{lb/d})}{(\quad 50{,}000 \quad \text{mg/l})} \times (120{,}000) = \underline{\qquad\qquad} \text{ gpd}$$

$$\text{Sludge Volume} = \frac{\text{Secondary Sludge Mass}}{\text{Secondary Sludge Concentration}}$$

$$\text{Sludge Volume} = \frac{(\qquad\qquad \text{lb/d})}{(\quad 10{,}000 \quad \text{mg/l})} \times (120{,}000) = \underline{\qquad\qquad} \text{ gpd}$$

Total Sludge Volume = ____________ gpd

Method 2 (Secondary Sludge Wasted to Primary):

$$\text{Total Sludge Volume} = \frac{\text{Total Sludge Mass}}{\text{Combined Sludge Concentration}}$$

$$\text{Total Sludge Volume} = \frac{(\qquad\qquad \text{lb/d})}{(\quad 30{,}000 \quad \text{mg/l})} \times (120{,}000) = \underline{\qquad\qquad} \text{ gpd}$$

Calculate Capability Sludge Handling Unit Processes:

1. Establish capability of *each* existing sludge handling process (treatment and disposal). The most common unit processes for which this calculation will have to be performed are:

   - Aerobic digestion
   - Anaerobic digestion
   - Gravity thickening
   - Mechanical dewatering
   - Drying beds
   - Liquid haul

For example, the capability of a gravity thickener is based on the maximum sludge loading it must handle:

$$\text{Thickener Loading} = \frac{\text{Total Sludge Mass}}{\text{Thickener Surface Area}}$$

$$\text{Thickener Loading} = \frac{(\qquad\qquad\qquad \text{lb/d})}{(\qquad\qquad\qquad \text{sq ft})} = \underline{\qquad\qquad} \text{ lb/d/sq ft}$$

2. Determine percentage of the expected sludge production that each process can handle.

Assume the sludge being thickened by the gravity thickener above is ABF. From Table 2-9, 4 lb/d/sq ft is considered typical loading for the thickener. Its capacity would therefore be calculated as:

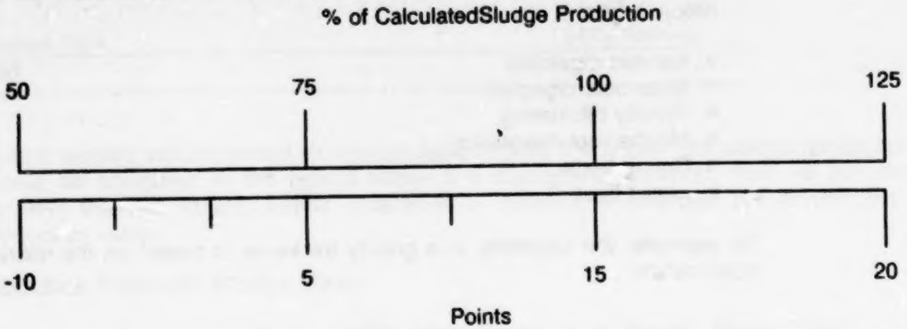
$$\frac{(\qquad 4 \qquad \text{lb/d/sq ft})}{(\quad \text{Actual Loading} \quad \text{lb/d/sq ft})} \times 100 = \underline{\qquad\qquad} \text{ percent}$$

List Each Process and Its Associated Sludge Handling Capability and Identify the Lowest Percentage Capability:

Process	Percentage

Lowest Capability = ____________

Determine Sludge Handling Capability Point Score:



Sludge Handling Capability Point Score = ______ ⑫

Add Scores 11 and 12 to Obtain Subtotal for Sludge Handling Capability:

Sludge Handling Capability Subtotal = ______ ⑬

Compare Subtotals and Total Score With Following to Determine Whether POTW is Type 1, 2, or 3:

		Points Required		
	Score	Type 1	Type 2	Type 3
"Aerator"	______ (5)	15-48	0-14	<0
Secondary Clarifier	______ (10)	20-55	0-19	<0
Sludge Handling Capability	______ (13)	10-30	0-9	<0
Total	______	50-133	15-49	<15

	Type
"Aerator"	______
Secondary Clarifier	______
Sludge Handling Capability	______
Total	______

Select the Worst Case: POTW is Type ______

Appendix P

Stabilization Pond Major Unit Process Evaluation Worksheet

This worksheet is used to evaluate the capability of existing major unit processes, i.e., aerator, secondary clarifier, and sludge handling system. Key loading and process parameters are compared with standard values and point scores are assigned. These points are subsequently compared with expected point scores for Type 1, Type 2, and Type 3 facilities, and a determination of the plant Type is made.

Instructions for use:

- Proceed through the steps contained in this worksheet *in order*.
- Use actual values in lieu of calculations if such data are available and appear reliable, e.g., waste sludge volume.
- When assigning points, interpolate and use the nearest whole number.
- Minimum and maximum point values are indicated - do not exceed the range illustrated.

Facultative Pond Facilities

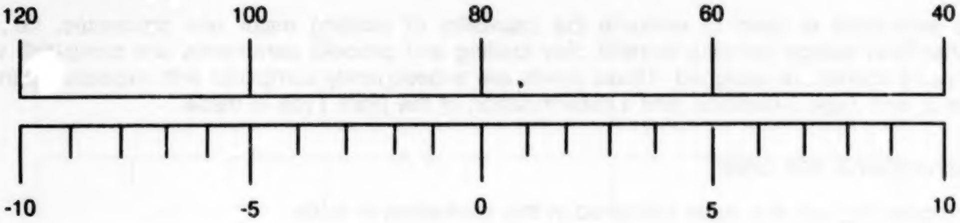
Calculate Total BOD_5 Loading:

$$\text{Total BOD}_5\text{ Loading} = \frac{\text{Average Daily BOD}_5\text{ Loading}}{\text{Total Surface Area of All Ponds}}$$

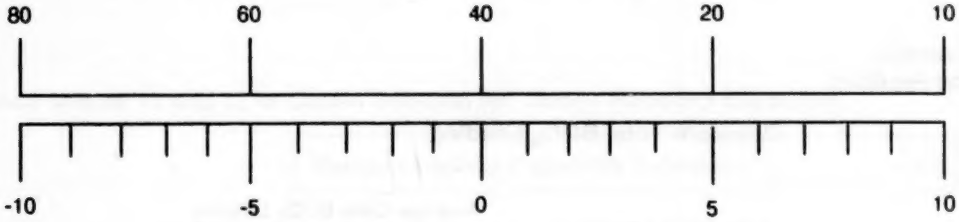
$$\text{Total BOD}_5\text{ Loading} = \frac{(\qquad\qquad\text{lb/d})}{(\qquad\qquad\text{ac})} = \underline{\qquad\qquad}\text{ lb BOD}_5\text{/ac/d}$$

Determine Total BOD_5 Loading Point Score:

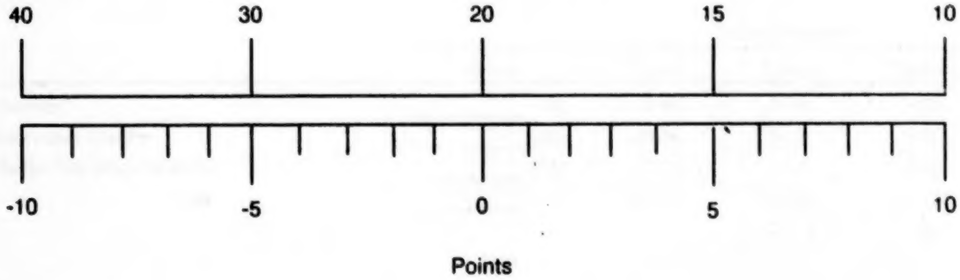
Total BOD_5 Loading (lb/ac/d) Average Winter Air Temperature >15°C


120
100
80
60
40
-10
-5
0
5
10

Total BOD_5 Loading (lb/ac/d) Average Winter Air Temperature 0-15°C


80
60
40
20
10
-10
-5
0
5
10

Total BOD_5 Loading (lb/ac/d) Average Winter Air Temperature <0°C


40
30
20
15
10
-10
-5
0
5
10
Points

Total BOD_5 Loading Point Score = ______ ①

Calculate 1st Pond BOD_5 Loading:

$$\text{1st Pond BOD}_5\text{ Loading} = \frac{\text{Average Daily BOD}_5\text{ Loading}}{\text{1st Pond Surface Area}}$$

$$= \frac{(\qquad\qquad\qquad \text{lb/d})}{(\qquad\qquad\qquad \text{ac})} = \_\_\_\_\_\_ \text{ lb BOD}_5\text{/ac/d}$$

Determine 1st Pond Loading Point Score:

Average Winter Air Temperature °C	1st Pond BOD_5 Loading lb/ac/d	Points
>15	>101	-3
	≤101	0
0-15	>73	-3
	≤73	0
<0	>39	-3
	≤39	0

1st Pond BOD_5 Loading Point Score = ___ ②

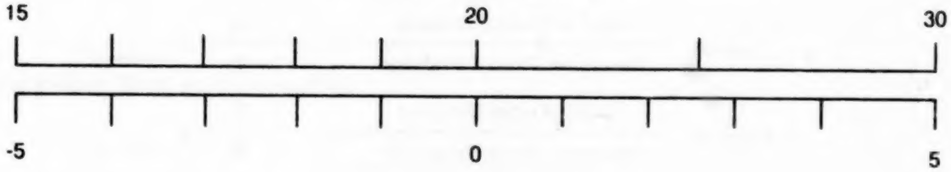
Calculate Detention Time:

$$\text{Detention Time} = \frac{\text{Total Pond Volume}}{\text{Average Daily Flow}}$$

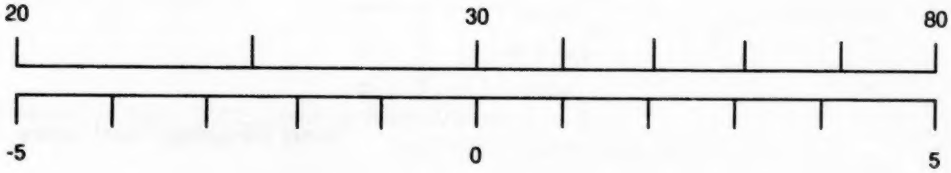
$$= \frac{(\qquad\qquad \text{cu ft})}{(\qquad\qquad \text{gpd})} \times 7.5 = \_\_\_\_\_\_ \text{ days}$$

Determine Detention Time Point Score:

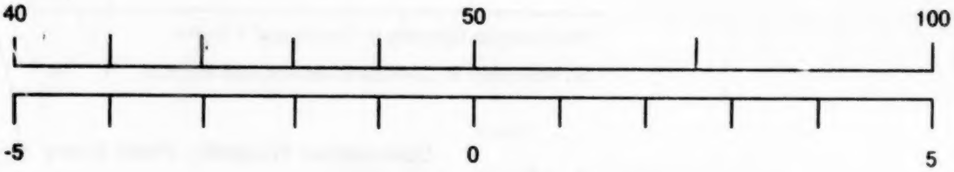
Detention time (days)



Average Winter Air Temperature >15°C



Average Winter Air Temperature 0-15°C

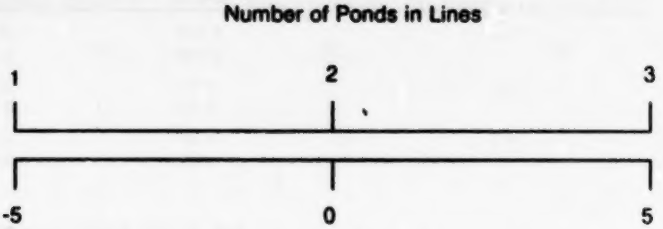


Average Winter Air Temperature <0°C

Points

Detention Time Point Score = ________ ③

Determine Number of Ponds in Series Point Score:



Number of Ponds in Series Point Score = __ ④

Determine Length-to-Width Ratio Point Score:

Length-to-Width Ratio	Points
>2	2
1.5 - 2	0
<1.5	-2

Length-to-Width Ratio Point Score = ______ ⑤

Determine Short Circuiting Ratio Point Score:

Pond #1 $\frac{\text{Inlet to Outlet Distance}}{\text{Maximum Pond Dimension}} = \frac{(\quad \text{ft})}{(\quad \text{ft})}$ = ______:1

Pond #2 $\frac{\text{Inlet to Outlet Distance}}{\text{Maximum Pond Dimension}} = \frac{(\quad \text{ft})}{(\quad \text{ft})}$ = ______:1

Average = _____:1

Average Short Circuiting Ratio	Points
>0.75	2
0.5 - 0.75	0
<0.5	-2

Short Circuiting Point Score = ______ ⑥

Determine Operational Flexibility Point Score:

	Points
Flexibility to Operate in Series and Parallel	3
No Flexibility to Operate in Series and Parallel	0

Operational Flexibility Point Score = ________ ⑦

Determine Variable Level Draw-Off Point Score:

	Points
Variable Level Draw-Off Available	3
Variable Level Draw-Off Not Available	-3

Variable Level Draw-Off Point Score = ________ ⑧

Add Scores 1 through 8 to Obtain Total Score

Facultative Pond Facilities Total Score = _______ ⑨

Determine Whether POTW is Type 1, Type 2, or Type 3:

		Points Required		
	Score	Type 1	Type 2	Type 3
Facultative Pond Facilities	______(9)	> 15	0-15	< 0

POTW is Type ____

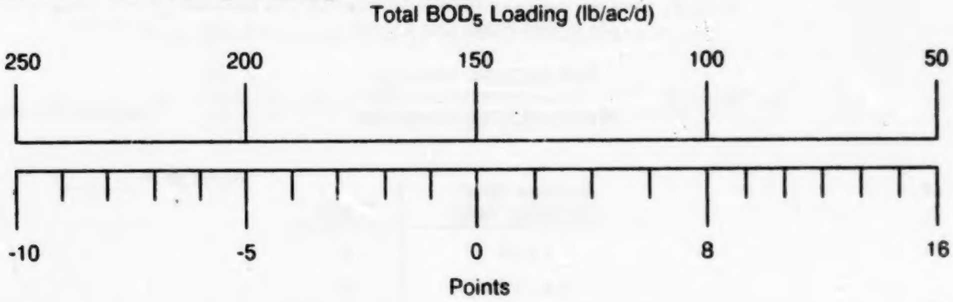
Aerobic Pond Facilities

Calculate Total BOD_5 Loading:

$$\text{Total } BOD_5 \text{ Loading} = \frac{\text{Average Daily } BOD_5 \text{ Loading}}{\text{Total Surface Area of All Ponds}}$$

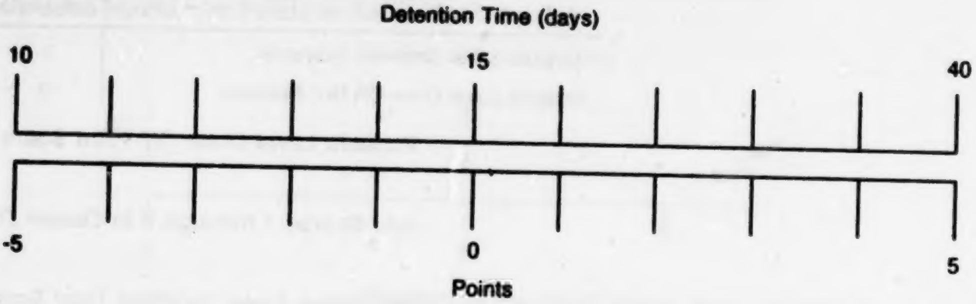
$$\text{Total } BOD_5 \text{ Loading} = \frac{(\qquad\qquad\qquad\qquad \text{lb/d})}{(\qquad\qquad\qquad\qquad \text{ac})} = \underline{\qquad\quad} \text{ lb } BOD_5\text{/ac/d}$$

Determine Total BOD_5 Loading Point Score:



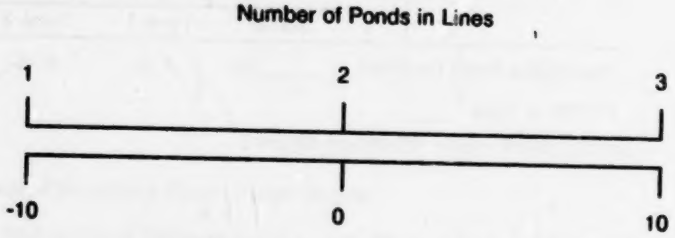
Total BOD_5 Loading Point Score = ________ ⑩

Determine Detention Time Point Score:


Detention Time (days)
10
15
40
-5
0
5
Points

Detention Time Point Score ________ ⑪

Determine Number of Ponds in Series Point Score:


Number of Ponds in Lines
1
2
3
-10
0
10

Number of Ponds in Series Point Score = ______ ⑫

Determine Length-to-Width Ratio Point Score:

Length-to-Width Ratio	Points
>2	2
1.5 - 2	0
<1.5	-2

Length-to-Width Ratio Point Score = ______ ⑬

Determine Short Circuiting Ratio Point Score:

Pond #1 $\frac{\text{Inlet to Outlet Distance}}{\text{Maximum Pond Dimension}} = \frac{(\quad \text{ft})}{(\quad \text{ft})}$ = ______:1

Pond #2 $\frac{\text{Inlet to Outlet Distance}}{\text{Maximum Pond Dimension}} = \frac{(\quad \text{ft})}{(\quad \text{ft})}$ = ______:1

Average = _____:1

Average Short Circuiting Ratio	Points
>0.75	2
0.5 - 0.75	0
<0.5	-2

Short Circuiting Point Score = ______ ⑭

Calculate Oxygen Availability:

Mechanical Aeration Systems

If data are not available on oxygen transfer capacity, calculate it as Wire Horsepower[1] (Appendix F) times Actual Oxygen Transfer Rate (Appendix E).

(__________hp) x (__________lb/hp-hr) x 24 = __________lb O_2/d

Diffused Air Aeration Systems

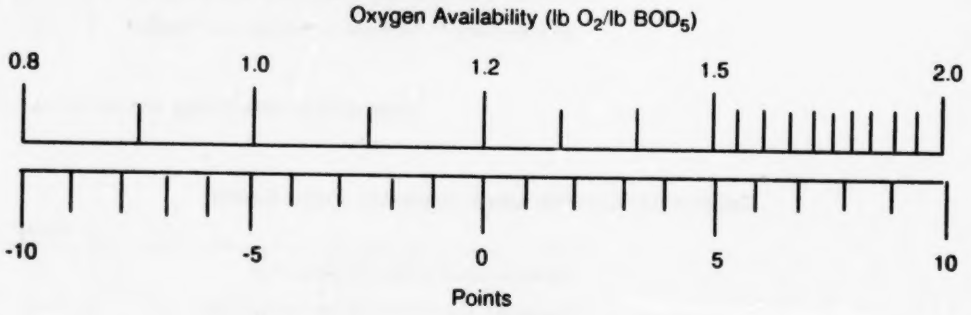
If data are not available on oxygen transfer capacity, calculate an actual oxygenation rate (Section 2.3.3.1).

__________lb O_2/d

$$\text{Oxygen Availability} = \frac{\text{Oxygen Transfer Capacity}}{\text{BOD}_5\text{ Loading to Aerator}}$$

$$\text{Oxygen Availability} = \frac{(\qquad\qquad \text{lb/d})}{(\qquad\qquad \text{lb/d})} = \_\_\_\_\_\_ \text{ lb } O_2/\text{lb BOD}_5$$

Determine Oxygen Availability Point Score:



Oxygen Availability Point Score = ________ ⑮

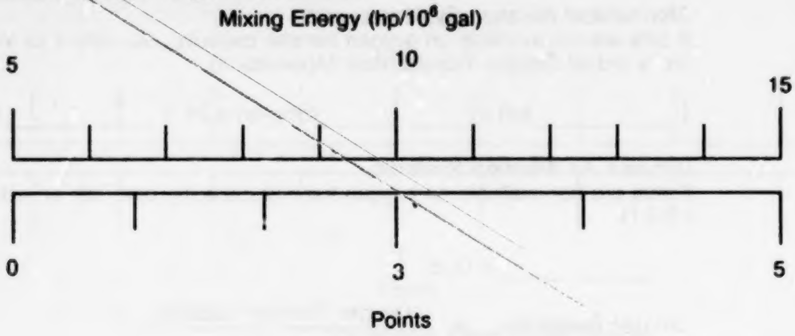
Calculate Mixing Energy:

$$\text{Mixing Energy} = \frac{\text{Total Energy in Primary Pond}^*}{\text{Primary Pond Volume}}$$

*Total energy includes energy used for aeration and mixing

$$\text{Mixing Energy} = \frac{(\qquad\qquad \text{hp})}{(\qquad\qquad 10^6 \text{ gal})} = \_\_\_\_\_\_ \text{ hp}/10^6 \text{ gal}$$

Determine Mixing Energy Point Score:



Mixing Energy Point Score = ______________ ⑯

Determine Operational Flexibility Point Score:

	Points
Flexibility to Operate in Series and Parallel	3
No Flexibility to Operate in Series and Parallel	0

Operational Flexibility Point Score = __________ ⑰

Determine Variable Level Draw-Off Point Score:

	Points
Variable Level Draw-Off Available	3
Variable Level Draw-Off Not Available	-3

Variable Level Draw-Off Point Score = ________ ⑱

Add Scores 10 through 18 to Obtain Total Score

Aerobic Pond Facilities Total Score = ________ ⑲

Determine Whether POTW is Type 1, Type 2, or Type 3:

		Points Required		
	Score	Type 1	Type 2	Type 3
Aerobic Pond Facilities	_____(19)	>20	5-20	<5

POTW is Type ____

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